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Roll Pass Design

Volume II

By
W. TRINKS
Professor of Mechanical Engineering
Carnegie Institute of Technology

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PREFACE

THE theories and explanations given in Vol. I of ROLL PASS DESIGN serve one object only, namely the design of rolls and roll passes. It is desirable to test the theories and to enlarge them by studying, one after another, the rolling of the commonly used sections. Such a study shows how far we can apply science, and where art and experience begin.

The very nature of such an investigation causes Vol. II to be less scientific than Vol. I and to approach being a collection of drawings of roll passes. A serious attempt has been made to keep this volume above the level of a mere collection by pointing out, for each section, the underlying theoretical and practical reasons for the shape and size of the passes. Comparison between different methods of rolling a given section also assists in making the book a treatise illustrating the application of principles rather than a catalogue of passes.

The appendix, containing information on the rolling of tubes and of nonferrous metals should make the volume of value to a larger circle of readers.

Sales records of the first edition show that the book is being studied not only by roll pass designers, but also by rollers and rolling mill superintendents. The argument is that a roller will do his work more intelligently, if he knows what is going on between the rolls.

While this second volume is complete in itself, repeated reference to Vol. I has been necessary in order to illustrate the principles.

Plates I to VII, inclusive, mentioned in the text, will be found in the pocket on the inside of the back cover.

Pittsburgh, Pa.
December, 1933.

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ROLL PASS DESIGN

Volume II

CHAPTER I
ROLLING OF SQUARE OR NEARLY SQUARE SECTIONS

Blooming Mill Passes

BLOOMS, that product of the blooming mill which gave the mill its name, are usually square, or of nearly square cross section. In that shape they can be pushed through a continuous furnace with the greatest safety. They travel on table rollers most easily, they can be stacked safely, and they can be rolled into smaller sections quite easily. Indeed, the square section has become the almost universal starting section for rolling the many shapes demanded by the trade. There are exceptions, but they are few in number.

For many years, ingots were cast square with rounded corners, and most ingots are even today of that cross section. With such ingots, the task of the blooming mill is to convert a large square into smaller squares. In recent years, corrugated or fluted ingots of generally square and also of almost circular cross section have been introduced. They are converted in a few passes into squares with round corners or still more recently, into octagons, which are then gradually changed to squares. The reasons for this change of practice are metallurgical and do not belong into a book which deals solely with the mechanical side of roll design. The roll designer has to adapt his work, as far as possible, to the requirements which result from the discoveries of the metallurgist.

The rolling of square blooms from practically square ingots has been well standardized in the United States, whereas the rolling of square blooms from round ingots using the octagon as intermediate section has not yet been standardized.

In the standard method of rolling blooms, the ingot or the bloom, or the intermediate product, lies flat on the roller table. for the sake of convenience; because the mill may be required to roll other products, such as slabs or beam blanks. Any grooves for diagonal rolling in the roller table would certainly be in the wrong place for different rolls and different sections; they would, moreover, interfere with the lateral shifting of the bloom which is necessary to direct it into the proper pass.

Rolling the ingot flat leads to the use of open box passes (for definition of name see page 4, Vol. I), which are, as a rule, placed on two-high mills, because only the two-high mill permits quick adjustment of center distance between rolls, and also because of the wish to obtain a roll of maximum strength. Such adjustment is necessary if different shapes are to be rolled on the mill. Closed passes are out of the question, because the rolled sections are deep compared to the roll diameter, and because, with that ratio, closed passes would cut more deeply into the rolls and would require collars which are too wide. The example shown in Fig. 150 and in Table VIII illustrates the method of rolling. It was taken from Camp and Francis (The Making, Shaping, and Treating of Steel) because it describes very well that method which was standard for many years and which is still used without change in many mills. While the author has drawings of many other blooming mill rolls, he has not the corresponding schedules of practice in rolling with them.

The dimensions of the section after each pass are those given in Camp and Francis' book. The extent of the projected contact area was calculated (as shown on page 26 of Vol. I) by multiplying the projected length of contact by the average width of the bar (ingot or bloom) in the pass. The values of the rate of compression and of the compression resistance are based upon a gradually increasing average speed of rolling

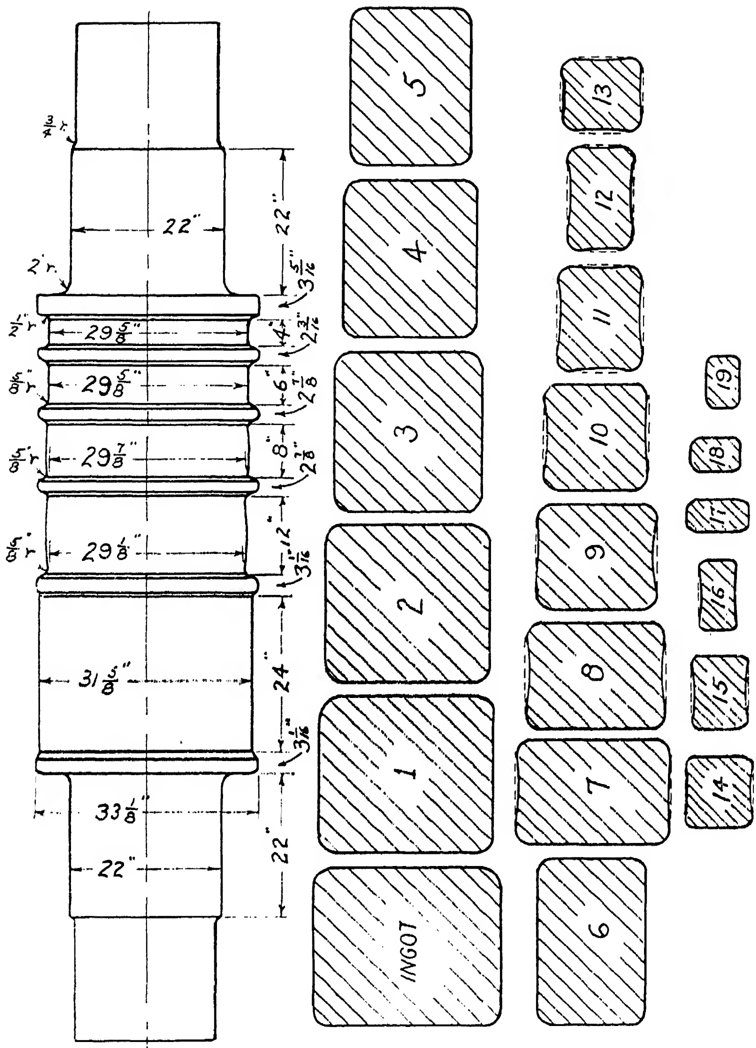


Fig. 150

as the bar becomes smaller in cross section and greater in length, beginning with 40 revolutions per minute in the first pass and ending with 140 revolutions per minute in the last pass. The values of torque in the seventeenth column of the table were

TABLE VIII

Number of Pass	Number of Groove	Minimum Width of Groove, in.	Average Dimensions of Leaving Section: Width, in.	Depth, in.	Area, sq. in.	Draft, sq. in.	Reduction, per cent	Projected Contact Length, in.	Projected Contact Area (Col. 9 × Average Width), sq. in.	Temperature of Bar (Estimated) degrees F.	Probable Maximum Roll Speed, r.p.m.	Rate of Compression, (1/sec.)	Compression Resistance 1000 lb./sq. in.	Total Separ. Force (Col. 10 × Col. 14) 1000 lb.	Lever Arm (Estimated) (Col. 9 × 0.5) in.	Torque, not includ. Roll Neck Friction 1000 (Col. 15 × Col. 16) in.-lbs.	Average Stress at Different Sections of Roll—1000 lb./sq. in.: Left Hd. Roll N'ck: Ideal Stress	Left Hd. Roll N'ck: Actual Stress	Ri'ht Hd. Roll N'ck: Ideal Stress	Ri'ht Hd. Roll N'ck: Actual Stress	Max. Stress in Body of Roll: Groove No.	Max. Stress in Body of Roll: Ideal Stress	Max. Stress in Body of Roll: Actual Stress	Average Horsepower (Estimated) Including Roll Neck Friction
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0			18.75	21.35	400																			
1	1	24	19.0	19.9	378	22	5.5	4.73	89.2	2200	40	0.94	6.5	580	2.37	1380	3.03	3.94	1.06	1.32	2	3.06	3.33	1460
2	1	24	19.3	18.4	355	23	6.09	4.82	92.4	2200	40	1.03	6.5	600	2.41	1450	3.13	4.06	1.10	1.36	2	3.16	3.45	1530
3	1	24	19.0	17.1	325	30	8.45	5.82	109.0	2200	40	1.28	6.6	713	2.91	2080	3.72	4.84	1.31	1.62	2	3.76	4.10	2200
4	1	24	19.3	15.4	297	28	8.62	5.13	98.2	2190	40	1.27	6.6	648	2.57	1668	3.38	4.39	1.18	1.47	2	3.42	3.73	1760
5	1	24	19.6	13.6	267	30	10.1	5.30	103.0	2180	60	2.19	7.8	803	2.65	2130	4.19	5.44	1.47	1.82	2	4.23	4.61	3370
6	1	24	19.8	11.9	236	31	11.6	5.13	101.0	2170	60	2.40	8.1	818	2.57	2110	4.27	5.54	1.50	1.86	2	4.32	4.71	3350
7	2	12	12.3	17.2	212	24	10.2	6.01	72.9	2150	60	1.96	8.1	590	3.01	1780	2.06	2.67	2.09	2.59	2	4.53	4.94	2810
8	2	12	12.5	15.2	190	22	10.4	5.31	66.0	2130	60	1.98	9.8	646	2.65	1713	2.26	2.93	2.29	2.84	2	4.96	5.40	2710
9	2	12	12.5	13.5	169	21	11.0	4.94	61.6	2110	80	2.76	12.2	748	2.47	1845	2.61	3.40	2.65	3.29	2	5.75	6.28	3900
10	2	12	12.7	11.5	146	23	13.6	5.31	67.0	2090	80	3.38	13.7	921	2.65	2440	3.22	4.18	3.26	4.03	2	7.08	7.70	5170
11	2	12	12.4	9.85	122	24	16.5	6.27	75.0	2070	80	4.26	13.1	983	3.13	3080	3.43	4.46	3.47	4.30	2	7.54	8.21	6510
12	2	12	12.7	7.5	95.2	26.8	22.0	5.73	72.0	2050	100	5.85	16.6	1195	2.86	3415	4.17	5.42	4.24	5.26	2	9.17	10.00	9000
13	3	8	8.06	9.72	78.4	16.8	17.7	6.50	50.5	2030	100	5.52	12.7	641	3.25	2090	1.80	2.34	2.72	3.38	2	4.85	5.29	5500
14	3	8	8.40	7.12	59.8	18.6	23.7	6.10	50.2	2010	100	6.75	18.2	913	3.05	2785	2.56	3.32	3.87	4.80	2	6.91	7.52	7350
15	3	8	7.75	6.00	46.5	13.3	22.3	5.86	43.6	1990	120	9.00	15.0	654	2.93	1920	1.83	2.38	2.77	3.43	2	4.95	5.40	6060
16	3	8	8.15	3.94	32.1	14.4	31.0	5.49	43.6	1960	120	11.70	20.0	872	2.74	2390	2.44	3.17	3.69	4.58	2	6.60	7.20	7570
17	5	4	4.20	6.84	28.7	3.4	10.6	4.35	17.7	1930	120	6.85	18.9	334	2.17	726	0.40	0.52	1.95	2.42	5	1.36	1.48	2300
18	5	4	4.32	5.72	24.7	4.0	13.9	4.04	17.2	1890	140	8.76	24.6	421	2.02	850	0.51	0.66	2.46	3.05	5	1.72	1.87	3140
19	4	6	6.10	3.97	24.2	0.5	2.02	2.24	13.3	1850	140	7.75	25.6	340	1.12	380	0.65	0.85	1.73	2.15	4	1.98	2.14	1400

(Roll neck friction assumed to be 40 per cent of total work, in all passes.)

This table refers to Fig. 150, page 3.

obtained by multiplying the value given in column 15 for each pass by that given in column 16 for the same pass. These values of torque do not include roll neck friction. If ordinary sliding bearings are used the torque in column 17 must be multiplied by about 1-2/3 to obtain the total torque. It should be understood that the values for the separating force (column 15) and the torque (column 17) are only approximate averages and are subject to variations within the length of each bloom, because neither speed of rolling nor temperature remains constant. The horsepower figures are based on the rolls accelerating from zero at the beginning of the pass to a maximum speed, then decelerating to zero at the end of the pass. Values in columns 18 to 24 represent bending stresses at the roots of the roll necks, and at the roots of the grooves in the roll body. In each case, the left hand column contains the ideal stress as found, if the bending moment is divided by the section modulus. The right hand column contains the probable stress, due attention having been paid to changes of cross section, radii of fillets, etc.

The calculation of stresses which is referred to here may be considered superfluous by some roll designers, because the rolls of a two-high blooming mill seldom break. Circumstances might arise, however, which would require the use of heavier reductions, or longer rolls with more passes, in which the calculation of stresses would become essential.

It will be noticed that the stresses in this blooming mill roll and in the one analyzed later on are quite low. It might, therefore, appear as if smaller or longer rolls could be used. In Germany, longer rolls are indeed used, and a blooming mill rolls a larger program than in the United States. But in Germany, the peripheral speed of rolling is low, and the additional impact stresses at the entrance of the ingot (which do not appear in the calculations) are much smaller.

The design of a blooming mill roll with a bullhead will be given later attention under the heading "Combined Slabbing and Blooming Mills." It will be seen that the roll in Fig. 150 has five grooves of different width, but of practically equal diameter. The first question that the young roll designer might

ing mill rolls to wear rapidly. Visual evidence of the side force and resulting wear is provided by the constant stream of sparks which issue from the collars.

These requirements explain the general shape of the blooming mill roll, and we now come to the second question: "Why is the diameter at the bottom of the grooves almost constant?" For an answer we must study the interaction between semi-finished bloom, bottom roll, and roller table. The sketch Fig. 152 shows that the diameter of the rolls should be such that the roll projects about one half of the draft (inches) above the roller table. Since the draft is approximately constant, the roll diameter must also be approximately constant. In the last pass the roll diameter is smaller, for the purpose of obtaining as deep a collar as possible. Depth of collars helps guiding. Side guards would be very inconvenient.

Going back to Table VIII we find from a study of the data given in the tabulation that the total reduction, in square inches, is low at first, rises rapidly, fluctuates up and down, and finally becomes quite low. This distribution of draft is characteristic of careful rolling. The first four passes are used for "squaring up," whereby the conicity of the ingot is removed, and for closing blowholes near the surface by welding the surfaces of the walls of the holes together. The dendritic structure of the ingot is also quite weak and must not be subject to heavy strains, which fact is another reason for the light, slow drafts of the first four passes. After that, reductions can be as heavy as the strength of the roll and the power of the motor or engine permit. However, the draft must never be so heavy that too much side pressure is exerted against the collars. In the early passes, ingots spread near the top and near the bottom, wearing out a pass as indicated in Fig. 153. The bloom then sticks in the rolls. Towards the end in the last passes, reductions are quite small, if a square, sharp cornered bloom is desired.

The roll designer is interested in the method of rolling far enough to ask this question: How many grooves and what size of grooves must I provide in the blooming mill roll? The primary factors which determine the answer to this question are the size

of the ingot which is to enter the rolls and the size of the bloom which is to be produced. First considering the bullhead pass, it is obvious that its width must be at least equal to the width of the ingot plus the spreading. The number of passes which the ingot receives in the bullhead is limited by the amount of reduction which can be made before edging. One reason for this limitation was explained in Vol. I—pages 74 to 76, namely that too great reduction without protection of the sides of the bar causes the steel to crack. Another reason for this limitation is that as soon as the surface of the ingot becomes colder than the interior, spreading will occur at the center of the ingot rather than at the top and bottom. (See Vol. I—page 97.) Before this stage of cooling is reached, the sides of the ingot must be made concave to counteract the central spreading. This requires

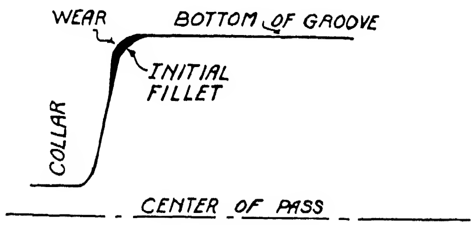


Fig. 153

edging in a groove with a belly. These factors determine the thickness of the bar as it leaves the bullhead pass; and because the bar is then edged, its thickness becomes the width in the next pass.

In the pass immediately following the bullhead pass, the sides and corners of the bar need no protection against cracking, because they have just been subjected to abundant direct compression. Consequently, some spreading can be allowed, and the width of the groove may be slightly greater than the width of the entering bar. The allowable reduction in this groove is limited by the same factors which were previously mentioned, and this limitation determines the number of passes which the bar receives in this groove. The width of the groove should be such that after the first pass in the groove the collars provide the corners of the bar with adequate protection against crack-

ing. This means that the natural spreading of the bar after the first pass should cause it to more than fill the entire width of the groove. In this way, the width of the groove is fixed within fairly definite limits, and similarly, the thickness of the bar leaving this groove may be used to determine the width of the following groove.

In designing intermediate grooves, however, it is necessary to consider intermediate sizes of blooms which may be required, and to alter the ideal or theoretical method of rolling so that such blooms may be produced. In general it is possible to roll a 20 x 20-inch ingot to an 8 x 8-inch bloom in three grooves, or to a 4 x 4-inch bloom in five grooves; but in that method of rolling it is difficult to produce intermediate sizes of blooms.

It will be noted that the belly becomes more pronounced as the groove becomes smaller. This is due to the fact that after a bloom has been rolled in a groove with a belly, its entrance in to a flat, wide groove might accidentally be made diagonally, which would result in a diamond-shaped billet. The depth of the collar seldom exceeds 3 inches, because a depth of 3 inches furnishes enough side protection even for an 8-inch bloom. The width of the collar at the root equals approximately its depth (for reasons, see Vol. I, pages 154, 155). The taper is as much as 10 degrees on the side.

With these data, the information for the roll designer is complete. However, he is probably curious to know whether the above described method of careful rolling is always followed. The answer is "no." An example is furnished by another set of rolls and passes likewise taken from Camp and Francis' book, tabulated in Table IX, and illustrated in Fig. 154. The data in this table were obtained in the same way as those of Table VIII. It can be seen that the draft is heavy in the first pass. The steel is not handled carefully, and cracks are apt to appear unless the steel is of high quality.

From this discussion it is evident that with a two-high reversing mill the roller has more influence on correct rolling than the roll designer. Even if a square ingot is used at the start.

the steel can be handled carefully and the surface blemishes can be reduced to a minimum, unless a high tonnage is required. Matters are different with a three-high blooming mill.

Rolls for Three-High Blooming Mills

Three-high blooming mills, unlike two-high reversing blooming mills, do not allow the rolling of several bloom sizes from one size of ingot in one given set of rolls, but are useful for rolling one and the same bloom with a given set of rolls. For moderate reduction, the capacity of a three-high bloomer is

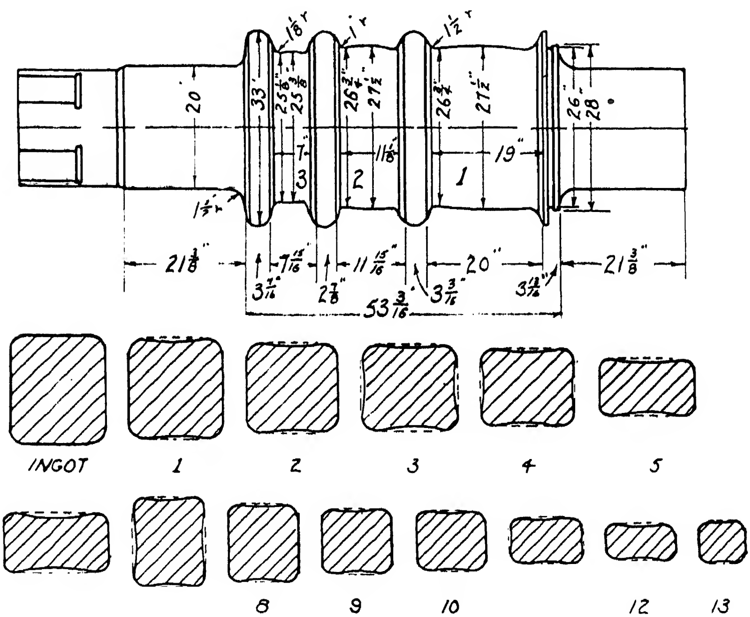


Fig. 154

much greater than that of a two-high reversing mill, but the steel is severely punished due to the quick deformations and the heavy drafts of the early passes. Some kinds of steel contain gas pockets (blow holes) near the skin of the ingot. These blow holes are torn open by the before-mentioned combination of quick deformation and heavy draft. Furthermore, the den-

TABLE IX

Number of Pass	Number of Groove	Minimum Width of Groove, in.	Dimensions of Leaving Section: Average Width, in.	Average Depth, in.	Area, sq. in.	Draft, sq. in.	Reduction, per cent	Projected Contact Length, in.	Projected Contact Area, sq. in. (Col. 9 × Average Width)	Temperature of Bar (Estimated) deg. F.	Probable Maximum Roll Speed, r.p.m.	Rate of Compression (1/sec.)	Compression Resistance 1000 lb./sq. in.	Total Resisting Force (Col. 10 × Col. 14) 1000 lb.	Lever Arm (Estimated) (Col. 9 × 0.5) in.	Torque, not including Roll Neck Friction (Col. 15 × Col. 16) 1000 in.-lb.	Average Stress at Different Sections of Roll—1000 lb./sq. in.: Left Hd. Roll N'ck: Ideal Stress	Left Hd. Roll N'ck: Actual Stress	Ri'ht Hd. Roll N'ck: Ideal Stress	Ri'ht Hd. Roll N'ck: Actual Stress	Max. Stress in Body of Roll: Groove Number	Max. Stress in Body of Roll: Ideal Stress	Max. Stress in Body of Roll: Actual Stress	Average Horsepower (Estimated) Including Roll Neck Friction
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0			18.8	21.4	402																			
1	1	19	18.8	19.3	363	39	9.70	5.24	98.5	2200	40	1.05	6.5	640	2.62	1680	1.81	2.30	4.00	5.09	1	3.90	4.11	1780
2	1	19	18.8	17.6	331	32	8.82	4.74	89.0	2200	40	1.05	6.5	579	2.37	1375	1.63	2.07	3.62	4.60	1	3.53	3.73	1450
3	1	19	18.3	16.3	298	33	9.97	5.69	102.0	2200	40	1.30	6.6	669	2.84	1900	1.89	2.40	4.18	5.31	1	4.08	4.31	2010
4	1	19	18.8	14.5	272	26	8.73	4.87	90.4	2190	40	1.27	6.6	597	2.43	1455	1.69	2.15	3.73	4.73	1	3.65	2.85	1540
5	1	19	19.1	12.8	244	28	10.3	4.74	89.6	2180	60	2.09	7.5	672	2.37	1595	1.90	2.41	4.20	5.33	1	4.11	4.34	2800
6	1	19	19.3	11.0	212	32	13.1	4.87	93.5	2170	60	2.43	8.1	757	2.43	1840	2.14	2.72	4.73	6.00	1	4.62	4.88	2910
7	2	11	11.6	16.5	191	21	9.90	6.01	68.0	2160	60	2.01	7.8	530	3.00	1590	2.86	3.63	1.95	2.48	2	3.90	4.21	2520
8	2	11	12.0	14.6	175	16	8.37	4.99	58.9	2150	80	2.59	9.3	546	2.49	1360	2.95	3.75	2.01	2.56	2	4.02	4.33	2870
9	2	11	12.2	12.8	156	19	10.9	4.87	59.0	2130	80	2.84	10.4	613	2.43	1490	3.31	4.20	2.26	2.86	2	4.52	4.88	3150
10	2	11	12.3	10.9	134	22	14.1	4.99	61.0	2110	80	3.34	13.5	823	2.49	2050	4.45	5.65	3.03	3.35	2	6.06	6.53	4330
11	2	11	11.7	8.93	104	30	22.4	6.35	71.7	2080	95	5.31	15.9	1140	3.17	3620	6.15	7.80	4.20	5.33	2	8.40	9.07	9100
12	2	11	11.8	6.54	77.7	26.3	25.3	5.40	63.5	2050	95	6.15	16.7	1060	2.70	2860	5.71	7.26	3.89	4.94	2	7.80	8.42	7160
13	3	7	7.07	8.17	57.8	19.9	25.6	6.56	44.6	2000	110	6.65	13.8	616	3.28	2020	4.38	5.57	1.20	1.53	3	4.20	4.53	5870

(Roll neck friction assumed to be 40 per cent of total work, in all passes.)

This table refers to Fig. 154.

dritic structure of the ingot causes cracks to appear, if the deformation is too rapid. All sorts of surface defects develop, and a heavy chipping bill is the inevitable outcome.

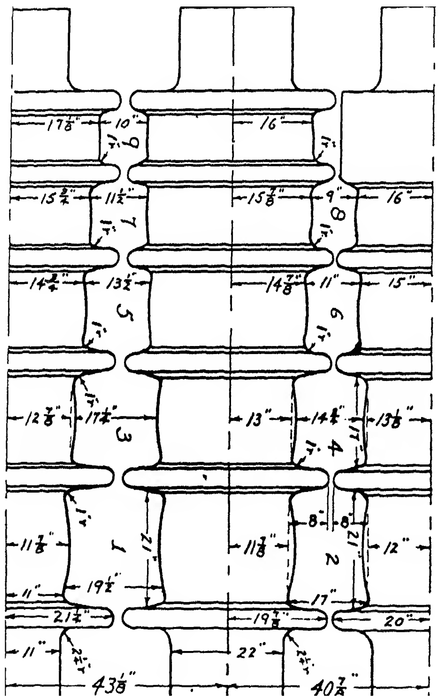
Nevertheless, roll design for a three-high blooming mill is interesting as well as instructive, and a considerable number of such mills are still in use. For these reasons the design of such rolls will be discussed at some length.

In order to save length of roll, we roll one pass over the other, which means that a groove in the middle roll must serve for both the top and the bottom roll. Manipulation and edging are safe only on the side toward the pulpit; in consequence only the bottom passes are edging passes. In further consequence, the draft in the bottom passes is much heavier than in the top passes, because heavy reduction of the edged bloom prevents too deep a grooving of the middle roll. In this method of rolling, edging occurs after each two passes. Passes 1 and 2 reduce the thickness of the ingot; then edging occurs, and passes 3 and 4 reduce the dimension which was the width of the ingot. Then comes another edging; passes 5 and 6 reduce the thickness of the bloom; etc.

Drafts are usually rather heavy in order to obtain the necessary reduction on a small mill. Each pair of passes (top and bottom) can be used only once per ingot, and a short roll can be obtained only by the use of heavy drafts, for the following reason. Light drafts mean many passes; many passes result in a great roll length, so that, for strength of roll, the passes must be spread over two rolls. It might appear that with light drafts, an increase in roll length should be permissible, but such a conclusion would be wrong. If reductions are lightened the projected contact area is reduced less rapidly than the draft. In order to obtain one half of the projected contact area, we must reduce the draft to one quarter of its original value, and since the separating force is very nearly proportional to the projected contact area the force is reduced not nearly as much as the draft. The bending moment, which is proportional to the product "force times roll length" grows as we work with lighter drafts.

Drafts are, therefore, made as heavy as strength of roll,

entering the ingot or the bloom into the rolls, and metallurgical conditions, permit. The latter are frequently disregarded, leaving strength of roll and entrance or biting requirements as the limiting features, possibly augmented by considerations of strength of driving engine or motor. Two examples will clarify the features that characterize the design of three-high blooming rolls. The first example is taken from Camp and Francis, "The Making, Shaping and Treating of Steel," fifth edition, pages 499 to 502.



The rolls are shown in Fig. 155. An inspection of the illustration shows that there are nine passes, that the collars have but little slope; that no room is allowed for spreading, and that the draft is heavier in the bottom passes than in the top passes (reasons for which were given above).

The reason for these facts, as given in Camp and Francis' book, is simple. The ingot of 21 x 23 inches cross section is to be rolled to a 9 x 10-inch bloom. The reduction calls for a draft of 12 inches on one side and 13 inches on the other, or a total of 25 inches. Since there are five bottom passes and four top passes, and since the roll designer considered it advisable to make the draft in the bottom heavier, the latter were designed for 3 inches draft each, and the top passes for 2½ inches. Five times three, plus four times two and one-half, equal 25 inches.

Table X contains data on dimensions of pass, area, draft, (square inches), reduction in per cent, entrance angle, projected contact area, product of contact area times average pressure, and product of separating force times lever arm. It will be noticed that the torque stays uniformly high, being greatest in the bottom passes.

Top roll, middle roll and bottom roll can be made alike, but the pitch between top and middle roll must be less than the pitch between middle and bottom rolls, so as to obtain a flatter pass, and reduction of the bloom above the middle roll. In the example in question, the top roll is slightly larger than the middle roll, and the latter is slightly larger than the bottom roll. On page 176, Vol. I, mention was made of the fact that this difference of roll diameter is most unusual for blooming mill rolls, because it keeps the heavy bloom down on the roller table and causes it to thump against each roller.

Since no spreading (or only insignificant spreading) is allowed, the collars receive a side thrust equal to 25 or 30 per cent of the spreading force. Wear is therefore considerable, and the rolls do not last long. They are turned ¾-inch oversize and are discarded when they are the same amount undersize. It is probable that flange abrasion determines the period of usefulness.

All passes of Fig. 155 have a belly. It has been claimed that the belly in three-high blooming mills offers the advantage of softening the blow which occurs when the ingot or bloom strikes the mill. After the third or fourth pass, the belly has the

TABLE X

Number of Pass	Number of Groove	Minimum Width of Groove, in.	Average Dimensions of Leaving Section: Width, in.	Depth, in.	Area, sq. in.	Draft, sq. in.	Reduction, per cent	Entrance Angle, degrees	Projected Contact Length, in.	Projected Contact Area (Col. 10 × Average Width) sq. in.	Temperature of Bar (Estimated), deg. F.	Rate of Compression (1/sec.)	Compression Resistance 1000 lb./sq. in.	Total Separat'g Force (Col. 11 × Col. 14) 1000 lb.	Lever Arm (Estimated) (Col. 10 × 0.5) in.	Torque, not including Roll Neck Friction (Col. 15 × Col. 16) 1000 in.-lb.	Average Stress of Different Sections of Roll—1000 lb./sq. in. Left Hd. Roll N'ck: Ideal Stress	Left Hd. Roll N'ck: Actual Stress	Ri'ht Hd. Roll N'ck: Ideal Stress	Ri'ht Hd. Roll N'ck: Actual Stress	Max. Stress in Body of Roll: Groove Number	Max. Stress in Body of Roll: Ideal Stress	Max. Stress in Body of Roll: Actual Stress	Estimated Horsepower Including Roll Neck Friction (Speed, 54 r.p.m.)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0			21	23	483																			
1	1	21	21	19.5	410	73	15.1	31.4	6.16	129.4	2200	1.6	8.4	1090	3.08	3350	1.43	1.96	6.20	6.67	1B	16.4	18.8	9560
2	2	21	21	17.0	357	53	12.9	26.5	5.34	112.0	2200	1.6	9.8	1100	2.67	2940	1.44	1.97	6.27	6.75	2M	13.2	15.1	8410
3	3	17	17	17.25	293	64	17.9	31.3	6.73	114.2	2200	1.9	9.1	1040	3.36	3500	2.82	3.87	4.46	4.80	1B	19.6	22.4	10000
4	4	17	17	14.75	251	42	14.3	25.1	5.55	94.3	2200	1.9	10.6	1000	2.77	2770	2.71	3.71	4.29	4.61	2M	15.1	17.2	7900
5	5	14.7	14.7	13.5	199	52	20.7	28.4	7.04	103.8	2180	2.4	9.6	995	3.52	3500	3.94	5.40	3.02	3.25	3B	13.8	15.5	10000
6	6	14.7	14.7	11.0	162.3	36.7	18.4	23.9	6.05	89.2	2150	2.6	12.1	1080	3.02	3260	4.28	5.87	3.28	3.52	4M	14.6	16.3	9300
7	7	11.0	11.0	11.5	126.5	35.8	22.0	26.4	7.06	77.5	2110	2.8	11.0	852	3.53	3020	4.32	5.91	1.65	1.77	3B	7.53	8.50	8630
8	8	11.0	11.0	9.0	99.0	27.5	21.7	23.1	6.25	68.7	2060	3.1	15.0	1030	3.12	3210	5.21	7.13	1.99	2.14	4M	8.86	9.90	9170
9	9	9.0	9.0	10.0	90.0	9.0	9.1	14.1	4.02	36.2	2000	2.1	12.1	438	2.01	884	2.63	3.60	0.44	0.48	3B	2.33	2.61	2520

This table refers to Fig. 155, page 14.

B stands for Bottom Roll
M stands for Middle Roll

TABLE XI

Number of Pass	Number of Groove	Minimum Width of Groove, in.	Average Dimensions of Leaving Section: Width, in.	Depth, in.	Area, sq. in.	Draft, sq. in.	Reduction, per cent	Entrance Angle, degrees	Projected Contact Length, in.	Projected Contact Area (Col. 10 × Average Width) sq. in.	Temperature of Bar (Estimated) deg. F.	Rate of Compression (1/sec.)	Compression Resistance 1000 lb./sq. in.	Total Separat'g Force (Col. 11 × Col. 14) 1000 lb.	Lever Arm (Estimated) (Col. 10 × 0.5) in.	Torque, not including Roll Neck Friction (Col. 15 × Col. 16) 1000 in.-lb.	Average Stress at Different Sections of Roll—1000 lb./sq. in.: Left Hd. Roll N'ck: Ideal Stress	Left Hd. Roll N'ck: Actual Stress	Ri'ht Hd. Roll N'ck: Ideal Stress	Ri'ht Hd. Roll N'ck: Actual Stress	Max. Stress in Body of Roll: Groove Number	Max. Stress in Body of Roll: Ideal Stress	Max. Stress in Body of Roll: Actual Stress	Estimated Horsepower Including Roll Neck Friction (Speed, 58 r.p.m.)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0			18	18	324																			
1	1	22.2	18.7	15.12	284	40	12.3	26.9	6.05	111.0	2220	2.1	7.3	810	3.02	2450	1.52	2.30	5.61	6.61	1B	7.1	7.5	7510
2	2	22.2	19.2	12.81	247	37	13.0	23.7	5.48	104.0	2220	2.3	7.4	770	2.74	2110	1.45	2.19	5.34	6.30	2M	6.4	6.8	6470
3	3	14.2	13.6	14.84	202.5	44.5	18.0	33.0	7.41	98.0	2210	2.5	8.9	872	3.70	3230	3.11	4.70	4.57	5.40	3B	10.7	11.5	9910
4	4	14.2	14.1	12.81	181.5	21	10.4	20.6	4.80	66.0	2210	2.2	10.1	668	2.40	1600	2.38	3.60	3.51	4.13	4M	8.17	8.8	4910
5	5	13.7	13.6	10.84	148	33.5	18.5	26.7	6.95	91.9	2200	3.1	11.5	1060	3.47	3670	5.33	8.05	4.00	4.71	3B	11.2	12.0	11250
6	6	13.7	13.7	8.84	121.5	26.5	17.9	20.8	5.55	75.8	2190	3.2	11.9	900	2.77	2500	4.53	6.84	3.40	4.00	4M	9.54	10.3	7660
7	7	9.7	9.6	10.56	101.7	19.8	16.3	26.0	6.88	63.5	2180	3.1	11.9	756	3.44	2610	4.74	7.16	1.92	2.26	3B	5.34	5.75	8000
8	8	9.7	9.7	8.56	83.5	18.2	17.9	20.7	5.54	53.6	2170	3.2	12.1	649	2.77	1800	4.07	6.16	1.65	1.95	4M	4.57	4.91	5510
9	9	9.5	9.3	6.69	62.4	21.1	25.3	24.0	7.17	64.1	2150	4.6	11.8	754	3.58	2700	5.53	8.35	1.11	1.31	7B	3.32	3.69	8260

This table refers to Fig. 156, page 19.

B stands for Bottom Roll
M stands for Middle Roll

purpose of preventing spreading in the center (see also page 97, Vol. I). It also offers a good place for the ragging.

The other example is illustrated in Fig. 156 and Table XI. This set of rolls also contains nine passes, the differences being that their collars are designed with much greater slope, and that sufficient room is allowed for spreading. Furthermore, the fillets at the bottom of the passes are larger whereby rapid cooling of the edges of the ingot and bloom are prevented. With the exception of grooves 1, 3, and 5, in the bottom roll, each groove used is provided with a belly. As in the previous example, the draft is greater in the bottom than in the top passes. The passes of Fig. 156 appear to have been thought out better than those of Fig. 155.

A comparison between two-high and three-high blooming rolls shows that the latter work with higher stresses. While impact is likely to be severe, stickers occur seldom. Cold steel which might stall a reversing engine or motor, would not stall a heavy flywheel.

The deformations are simple and easily understood.

The growth of the alloy steel business has caused the wish to roll mild steel and alloy steel in the same mill and to use the same rolls for both materials. The attempt, as a rule, does not meet with success. The resistance of most alloy steels against compression is so much greater than that of mild steel, that the rolls break. The characteristic properties of different alloy steels vary within wide limits, which means that general rules cannot be given. Wherever possible, drafts should be reduced to 70 per cent of those used with mild steel. If that is impossible, rolls can be made of forged nickel steel and spreading should be restrained but little by collars, because friction between bar and side collars requires power and increases the separating force. Furthermore, the difference between diameters of top and bottom roll should be made very small, because that difference causes friction, which also increases the separating force. Finally, it pays in some cases to work with heavier draft in the first passes and lighten up in the last passes, because some of the alloy steels, while almost as soft as mild steel when hot, become resistant at lower temperatures.

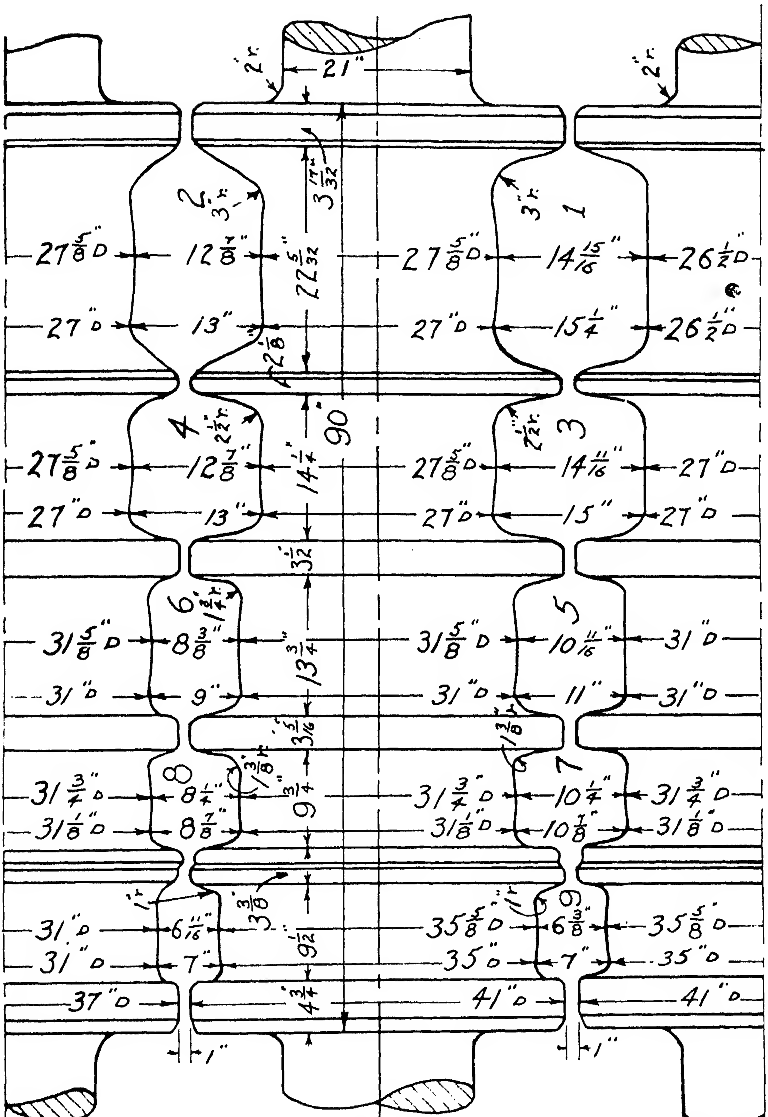


Fig. 156

At this point it is advisable to realize that the three-high blooming mill has certain limitations. For the sake of economy in rolls, we desire very much to make top, middle, and

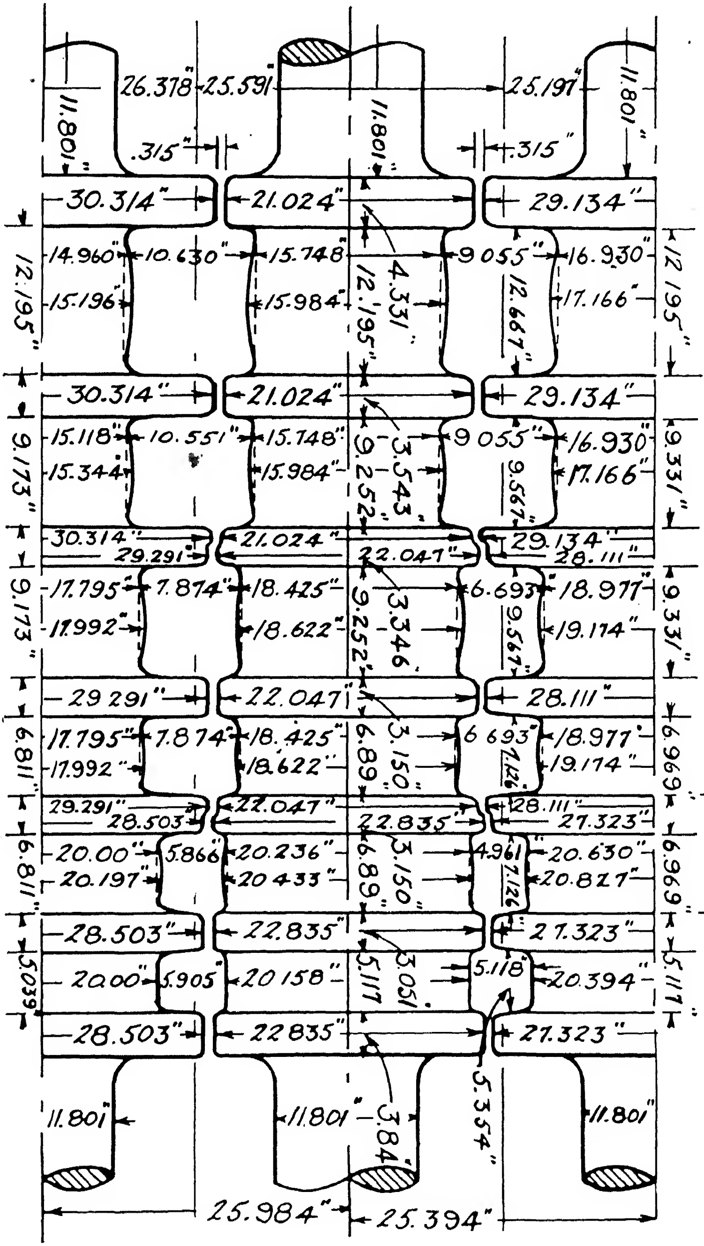
bottom roll practically alike. If that be done, and if the distance from center of top roll to center of middle roll were equal to the distance from center of middle roll to center of bottom roll, then there would be and could be no reduction or draft in the upper passes. To obtain such draft, we must pull the bottom roll away from the middle roll. The draft in each pass of the top row then becomes exactly equal to the difference between the center distances. And since the draft in the upper passes is constant, while the area of the bar becomes progressively smaller, the reduction in per cent must go up. And that action is quite contrary to the effect which we desire to obtain in rolling alloy steels.

A set of rolls which avoids this difficulty is shown in Fig. 157. As may be expected, top, middle, and bottom rolls are *not* alike.

Two-High Tandem Blooming Mills

It has already been mentioned that the two-high (screw down) reversing mill and even more so, the three-high blooming mill are hard on steel. Firstly, the speed of deformation is high, and secondly, box passes are used, which do not protect the sides sufficiently. The two-high mill works with box passes, because it is a general purpose mill and must, therefore, carry ingot and bloom on flat rollers. The three-high mill works with flat box passes not as a necessity, but for ease of shifting from one pass to the other.

It has been attempted to overcome these drawbacks by two-high mills with so-called monkey rolls, which roll more slowly than a reversing mill. The rolls are arranged in series or tandem and are set at such distances apart that the bloom when entering one set of rolls has left the preceding set of rolls. Each roll has only one pass or groove; no lateral shifting occurs. The size and shape of the bloom are constant. We can, therefore, use either box passes or oval and diamond passes. The latter two passes are frequently used in continuous mills; their application to blooming mills is of comparatively recent origin.


26.378"
25.591"
25.191"
11.801"
11.801"
11.801"
.315"
.315"
30.314"
21.024"
29.134"
12.195"
14.960"
10.630"
15.748"
4.331"
9.055"
16.930"
12.195"
15.196"
15.984"
12.195"
12.667"
17.166"
30.314"
21.024"
29.134"
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18.977"
9.331"
17.992"
18.622"
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27.323"
5.039"
20.00"
5.905"
20.158"
3.051"
5.118"
20.394"
5.117"
5.117"
28.503"
22.835"
27.323"
11.801"
11.801"
3.84"
5.354"
11.801"
25.984"
25.394"

Fig. 157

Fig. 158 illustrates a set of passes in which 10-inch by 10-inch ingots are converted into 6½-inch by 6½-inch blooms. On account of their similarity with billet mill passes they will not be discussed in detail in the present chapter. It may be men-

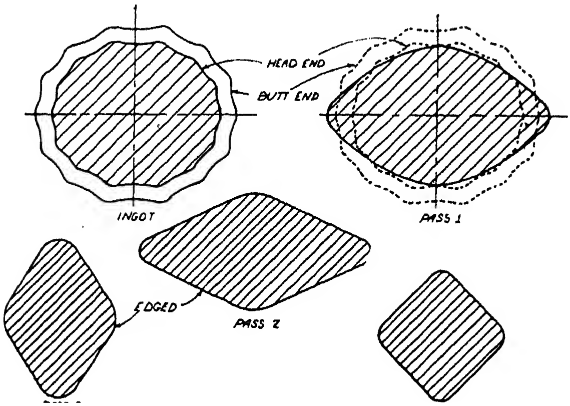


Fig. 158

tioned, however, that the spreading is quite small because of the uniform temperature in the ingot and bloom. The tabulation of Table XII furnishes data on the passes. The slow motion, coupled with compression from all sides is claimed to produce excellent blooms. The rolls for the four stands of which this mill consists are shown in Fig. 159.

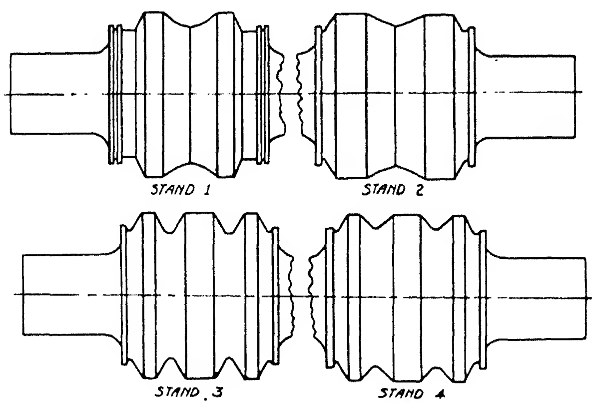


Fig. 159

TABLE XII

Number of Pass	Number of Groove	Width of Groove, in.	Average Dimensions of Leaving Section: Average Width, in.	Average Dimensions of Leaving Section: Average Depth, in.	Average Dimensions of Leaving Section: Area, sq. in.	Draft, sq. in.	Reduction, per cent	Projected Contact Length, Average, in.	Projected Contact Area (By Planimeter) sq. in.	Temperature of Bar, (Estimated) deg F.	Delivery Speed of Bar feet/minute	Rate of Compression (1/sec)	Compression of Resistance 1000 lb./sq. in.	Total Separating Force (Col. 14 × Col. 10) 1000 lb.	Lever Arm (Estimated) (0.5 × Col. 9) in.	Torque, not Including Roll Neck Friction (Col. 15 × Col. 16) 1000 in.-lb.	Average Horsepower (Estimated) Including Roll Neck Friction
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0			10.0	10.0	100.0												
1	1	14.50	14.5	9.38	85.4	14.6	14.6	6.00	48.0	2200	30	0.146	6.3	303	3.00	909	220
2	2	15.50	15.0	7.63	63.1	22.3	26.1	5.57	76.1	2200	40	0.375	6.4	486	2.78	1350	280
3	3	7.88	8.06	10.88	51.5	11.6	18.4	6.63	48.75	2180	50	0.278	6.4	312	3.31	1033	289
4	4	8.59	8.31	8.20	39.4	12.1	23.5	5.19	35.65	2150	60	0.544	7.3	261	2.59	677	232

This table refers to Fig. 158, page 22.

Fig. 160 illustrates a set of nine passes in which 22-inch square tapered ingots are reduced to 7½-inch by 7½-inch blooms. Edging is performed after each pass. The illustration, which includes only one-fourth of each cross section, shows the ingot and even-numbered passes in broken outline, and the odd-numbered passes in solid outline. Data pertaining to these passes are given in Table XIII. These passes are used in a semi-continuous or tandem mill which, like the preceding example, rolls very slowly. The torque and horsepower requirements are low, as shown by the table.

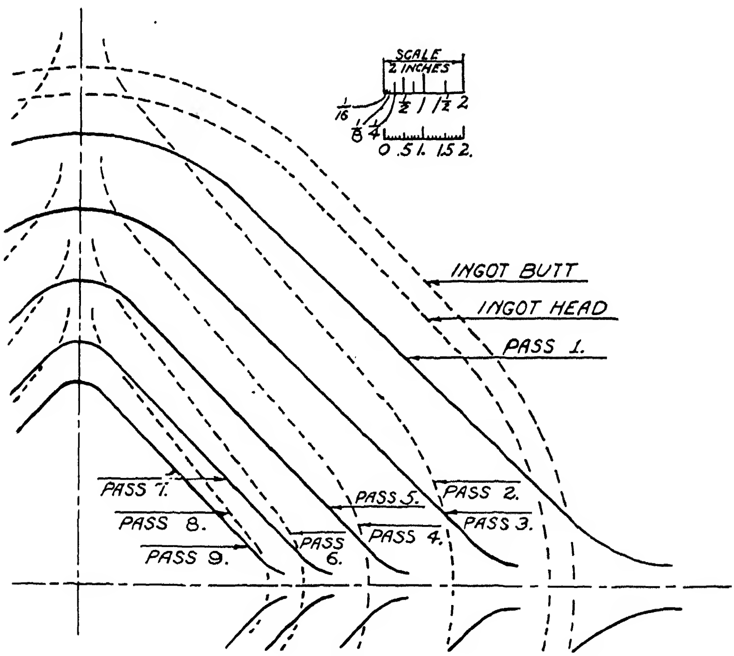


Fig. 160

The shape of the passes is discussed under the heading of billet mills, on a later page.

Roll Passes for Billets

Billets are semifinished bars, usually square, ranging in size from about 1½ x 1½ inches to about 5 x 5 inches. Accuracy

TABLE XIII

Number of Pass	Width of Groove, in.	Section				Elongation		Maximum Angle of Contact, degrees	Average Length of Contact, in.	Area of Contact (By Planimeter) sq. in.	Roll Speed, r.p.m.	Average Rate of Compression, (1/sec.)	Estimated Temperature deg. F.	Compression Resistance 1000 lb./sq. in.	Total Separating Force (Col. 11 × Col. 15) 1000 lb.	Lever Arm (Estimated) (Col. 10 × 0.5) in.	Estim. Torque, not includ. Roll Neck Friction (Col. 16 × Col. 17) 1000 in.-lb.	Estimated Horsepower Including Roll Neck Friction
		Width Along Diagonal, in.	Area, sq. in.	Draft, sq. in.	Reduction per cent	This Pass	Total											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
*I.H. ..		21.5	Mean															
†I.B.		22.75	490															
1	27.15	19.31	352	38.0	7.8	1.39	1.39	30.6	6.95	166.3	7.1	0.138	2200	6.7	1120	3.47	3890	1460
2	25.31	17.5	288	64.0	18.2	1.22	1.70	42.1	7.30	153.0	7.1	0.327	2200	7.0	1070	3.65	3900	1470
3	20.22	15.0	220	68.0	23.6	1.31	2.23	33.2	6.10	114.5	11.3	0.835	2200	7.2	825	3.05	2520	1510
4	18.94	13.31	172	48.0	21.9	1.28	2.35	33.2	7.15	130.5	11.3	0.680	2190	7.2	940	3.57	3360	2010
5	15.75	11.5	130	42.0	24.4	1.33	3.77	39.0	5.49	82.6	40.2	2.46	2180	9.6	793	2.74	2180	4630
6	15.63	10.13	102	28.0	21.6	1.28	4.81	34.4	4.52	67.0	40.2	2.78	2170	10.0	670	2.26	1510	3210
7	12.22	9.0	80	22.0	21.6	1.28	6.12	32.7	4.71	54.6	40.2	2.57	2150	10.3	563	2.35	1330	2830
8	12.18	8.25	66.6	13.4	16.8	1.20	7.38	26.6	3.48	40.4	40.2	2.40	2130	10.5	424	1.74	738	1570
9	10.09	7.5	55.4	11.2	16.9	1.20	8.84	25.6	4.02	39.1	50.7	3.15	2100	12.0	470	2.01	946	2530

*I.H.—Ingot Head
†I.B.—Ingot Butt

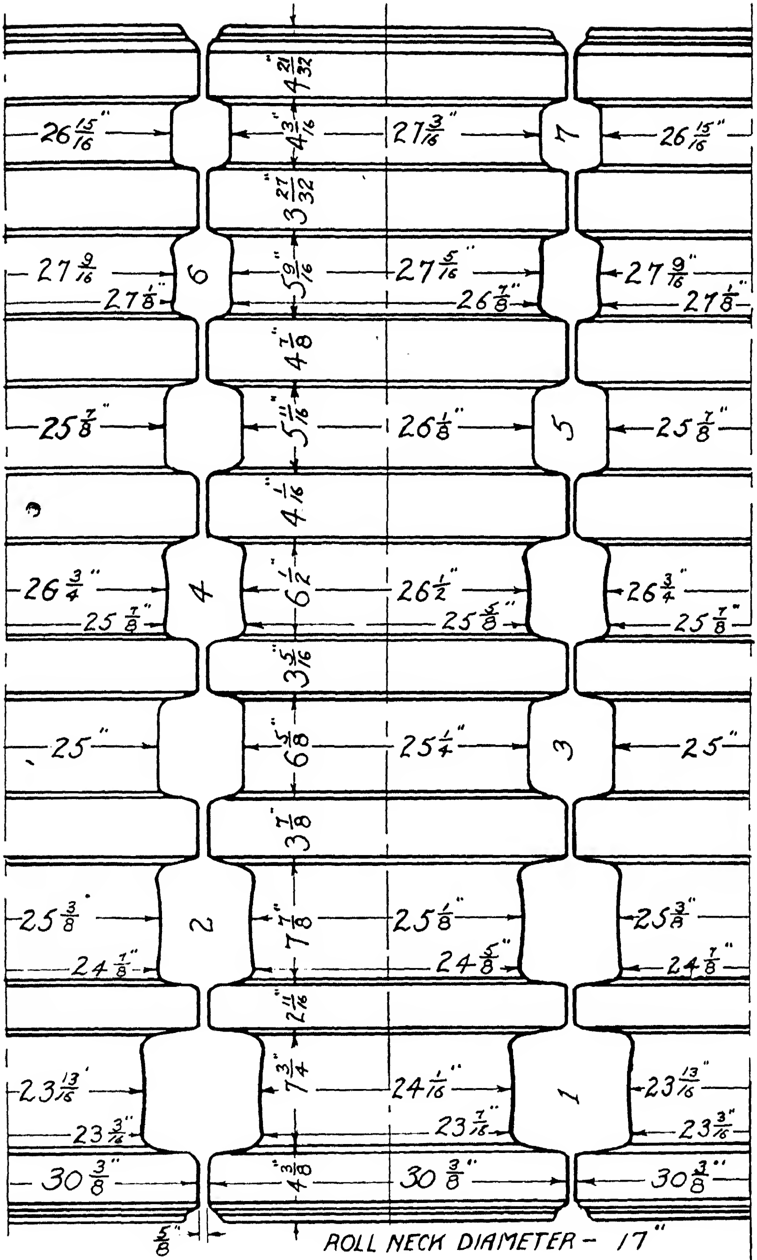
This table refers to Fig. 160, page 24.

and sharpness of corners are no object, but straightness of the delivered and cooled bar is of importance; likewise, absence of seams and cracks is helpful.

Billets are rolled on three-high mills which are similar to three-high blooming mills. They are also rolled in the roughing rolls of bar mills and also on continuous mills; usually on the latter, because billets are an article of mass production, and also because compression from all four sides can be obtained in the continuous mill (as well as in preparatory roughing rolls) by rolling the bar on the diagonal. It is true that the bar can be rolled on the diagonal in a three-high mill. However, that method of rolling causes difficulties with the approach and delivery tables, for this reason: In order to transport and guide the bar properly while it is being rolled on the diagonal, the table rollers should be provided with triangular grooves. These grooves would fit only one set of main rolls and it would be necessary to change table rollers every time the main rolls were changed. If, on the other hand, billets are rolled flat in box passes, the table rollers can be cylindrical (or "flat") no matter what size of billet is being rolled. In the roughing rolls of three-high merchant mills the billets likewise receive compression from all sides; but in this case the billet passes are hand passes and are solely preparatory to other passes.

In three-high mills, billets are, as a rule, rolled in alternate passes as indicated in Fig. 140 on page 180, Part I. Only in the first set of passes (or very seldom in two sets of passes) is one pass rolled over the other, and that only if we start with a large bloom. The reason for the difference between blooming mill practice and billet mill practice is the following: The collars between passes are thicker in the blooming mill than in the billet mill. Side guards and manipulator bars must be narrower than the collars. The smaller the billet, the flimsier the side guards. They are, for most billet passes, too flimsy to be safe. Furthermore, we can almost always place enough passes on the roll without having to roll one pass over the other.

Fig. 161 is a typical three-high billet roll, which operates at a fairly constant speed of 62 revolutions per minute. An


26 15/16"
7
27 3/16"
26 15/16"
4 21/32"
4 3/16"
3 27/32"
27 9/16
27 1/8"
6
5 9/16"
27 5/16"
26 7/8"
27 9/16"
27 1/8"
4 7/8"
25 7/8"
5 11/16"
26 1/8"
5
25 7/8"
4 1/16"
26 3/4"
25 7/8"
4
6 1/2"
26 1/2"
25 5/8"
26 3/4"
25 7/8"
3 5/16"
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25 3/8
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25 3/8"
24 7/8"
2 11/16"
23 13/16
23 3/16"
7 3/4"
24 1/16"
23 7/16"
1
23 13/16"
23 3/16"
30 3/8"
4 3/8"
30 3/8"
30 3/8"
5/8"
ROLL NECK DIAMETER – 17"

Fig. 161

analysis of the roll passes is contained in Table XIV. The method of analysis is identical with that used for blooming mill rolls, except that more than one bar is rolled at a time. The practice in operating this mill is to roll three bars at a time as frequently as possible, in the following order; passes 1-3-5, 2-4-6, 3-5-7, 4-6, 1-5-7, 2-6, 1-3-7, 2-4, 1-3-5, etc. The maximum requirements of horsepower and roll strength will of course occur during the passes in which three bars are rolled simultaneously. For this reason, the latter part of Table XIV contains strength and power requirements during those passes. With three bars between the rolls, the power requirement exceeds the capacity of the engine or motor, and the energy of the flywheel is depended upon to roll the shortest bar through the mill.

A study of the roll (still referring to Fig. 161) reveals three passes (No. 3, 5, 7) without a belly. They are the passes in which edging is done. Billets from any one of these passes can be withdrawn from the mill. The drawing further shows that, at the left where wide collars are needed for strength, the collars are narrow, while they are wide on the right hand side where wide collars are not needed for strength. Grooves in table rollers, for shifting and edging fingers, require the wide collars.

The rolls of another three-high billet mill are illustrated in Fig. 162. This mill operates at a speed of 80 revolutions per minute. In this case each groove has a belly, with the exception of those used for passes 1, 2 and 7. This set of passes is a working example of the fact that billets which are rolled in two consecutive passes without bellies need not necessarily form fins in the succeeding edging passes. It is probable that the stresses caused by impact in the first two passes of these rolls are greater, due to the absence of the belly, than in the rolls shown in Fig. 161. The fact that these passes are located at the ends of the rolls, however, demonstrates good design from the standpoint of roll strength.

Detailed data regarding these passes are given in Table XV. As is indicated in the table, the practice in operating this mill is to roll two bars simultaneously as frequently as possible, in the following order; passes 1-5, 2-6, 3-7, 4, 1-5, etc. The esti-

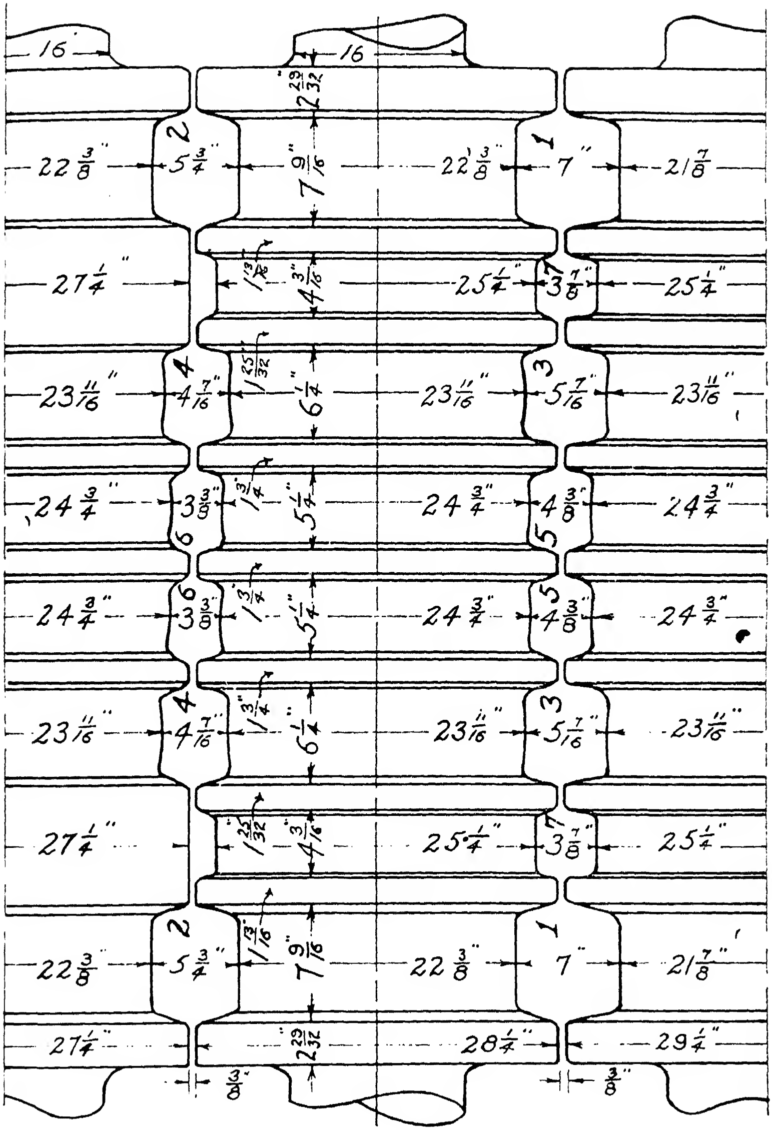


Fig 162

mated values of horsepower and stress for these simultaneous passes are given in columns 18 to 27 of the table. It will be observed that the values of stress are rather low. These rolls are

TABLE XIV

Number of Pass	Number of Groove	Average Width of Groove, in.	Dimensions of Leaving Sec.: Average Width, in.	Dimensions of Leaving Sec.: Average Depth, in.	Dimensions of Leaving Sec.: Area, sq. in.	Draft, sq. in.	Reduction, per cent	Projected Contact Length, in.	Angle of Contact, degrees	Projected Contact Area (Col. 9 × Average Width) sq. in.	Estimated Temperature Deg. F.	Rate of Compression (1/sec.)	Compression Resistance 1000 lb./sq. in.	Total Sep. Force (Col. 14 × Col. 11) 1000 lb.	Lever Arm (Estimated) (Col. 9 × 0.5) in.	Torque, not including Roll Neck Friction (Col. 15 × Col. 16) 1000 in.-lb.	Estimated Horsepower (Including Roll Neck Friction) at 62 r.p.m.	Simultaneous Passes	Total Estimated Horsepower	Average Stress at Different Sections of Roll—1000 lb./sq. in.: Left Hd. Roll N'k: Ideal Stress	Left Hd. Roll N'k: Actual Stress	Ri't Hd. Roll N'k: Ideal Stress	Ri't Hd. Roll N'k: Actual Stress	Max. Stress in Roll Body: Groove Number	Max. Stress in Roll Body: Ideal Stress	Max. Stress in Roll Body: Actual Stress
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
0			7.25	8.50	61.6																					
1	1	7.38	7.38	7.38	54.4	7.2	11.7	3.60	17.8	26.3	2050	3.02	14.2	373	1.80	672	2210	1-3-5	7260	9.3	11.2	6.1	7.9	3L	10.2	11.2
2	2	7.50	7.50	6.00	45.0	9.4	17.3	4.10	19.1	30.4	2040	3.67	15.1	460	2.05	942	3090	2-4-6	8090	8.8	10.6	9.1	11.9	3T	11.1	12.2
3	3	6.50	6.40	5.88	37.6	7.4	16.4	4.44	21.6	27.5	2030	3.92	13.7	376	2.22	835	2740	1-5-7	7230	7.0	8.4	8.3	10.8	5L	6.8	7.3
4	4	6.50	6.50	4.81	31.3	6.3	16.8	3.70	16.5	23.9	2010	4.15	16.4	391	1.85	723	2370	1-3-7	7660	8.4	10.1	7.5	9.8	3L	8.4	9.3
5	5	5.50	5.19	5.00	25.9	5.4	17.3	4.35	19.6	21.8	1990	4.43	14.9	324	2.17	703	2310	3-5-7	7760	5.7	6.9	9.6	12.5	3L	9.5	10.5
6	6	5.44	5.44	3.81	20.7	5.2	20.1	3.99	17.0	21.2	1960	5.24	18.9	401	2.00	802	2630									
7	7	4.13	4.13	3.88	16.0	4.7	22.7	4.54	19.6	18.0	1920	5.52	20.2	364	2.27	826	2710									

This table refers to Fig. 161, page 27.

TABLE XV

Number of Pass	Number of Groove	Average Width of Groove, in.	Dimensions of Leaving Sec. Average Width, in.	Dimensions of Leaving Sec. Average Depth, in.	Dimensions of Leaving Sec. Area, sq. in.	Draft, sq. in.	Reduction, per cent	Projected Contact Length, in.	Angle of Contact degrees	Projected Contact Area, sq. in. (Col. 9 × Average Width)	Estimated Temperature deg. F.	Rate of Compression (1/seconds)	Compression Resistance 1000 lb./sq. in.	Total Separat'g Force (Col. 14 × Col. 11) 1000 lb.	Lever Arm (Estimated) (Col. 9 × 0.5) in.	Torque, not Including Roll Neck Friction (Col. 15 × Col. 16) 1000 in.-lb.	Estimated Horsepower Including Roll Neck Friction (Speed, 80 r.p.m.)	Simultaneous Passes	Total Horsepower (Estimated)	Average Stress at Different Sections of Roll—1000 lb./sq. in.: Left Hd. Roll N'k Ideal Stress	Left Hd. Roll N'k Actual Stress	Ri't Hd. Roll N'k Ideal Stress	Ri't Hd. Roll N'k Actual Stress	Max. Stress in Roll Body Groove Number	Max. Stress in Roll Body Ideal Stress	Max. Stress in Roll Body Actual Stress
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
0 ..			6.69	9.32	62.4																					
1 ..	1	7.13	7.13	7.00	49.9	12.5	20.0	4.94	26.5	34.1	2050	4.46	13.9	474	2.47	1170	4940	1–5	8110	9.2	11.7	4.6	5.9	1B	7.5	9.1
2 ..	2	7.13	7.13	5.75	41.0	8.9	17.8	3.70	19.3	26.4	2040	4.49	16.2	427	1.85	791	3350	2–6	5850	8.4	10.7	4.3	5.5	2M	6.4	7.8
3 ..	3	6.00	6.00	5.59	33.5	7.5	18.3	4.19	20.9	24.6	2030	5.02	16.9	415	2.09	867	3660	3–7	5880	5.7	7.2	5.9	7.5	3B	7.5	8.0
4 ..	4	6.00	6.00	4.59	27.5	6.0	17.9	3.39	16.8	20.3	2010	5.15	17.5	356	1.69	601	2550	4	2550	3.8	4.8	2.1	2.7	4M	4.8	5.2
5 ..	5	5.00	5.00	4.56	22.8	4.7	17.1	4.14	19.8	19.8	1990	5.88	18.3	362	2.07	750	3170									
6 ..	6	5.00	5.00	3.56	17.8	5.0	21.9	3.47	16.2	17.4	1970	6.45	19.5	340	1.73	590	2500									
7 ..	7	4.00	4.00	3.88	15.5	2.3	12.9	3.72	17.1	14.1	1950	6.32	20.0	282	1.86	524	2220									

This table refers to Fig. 162, page 29.

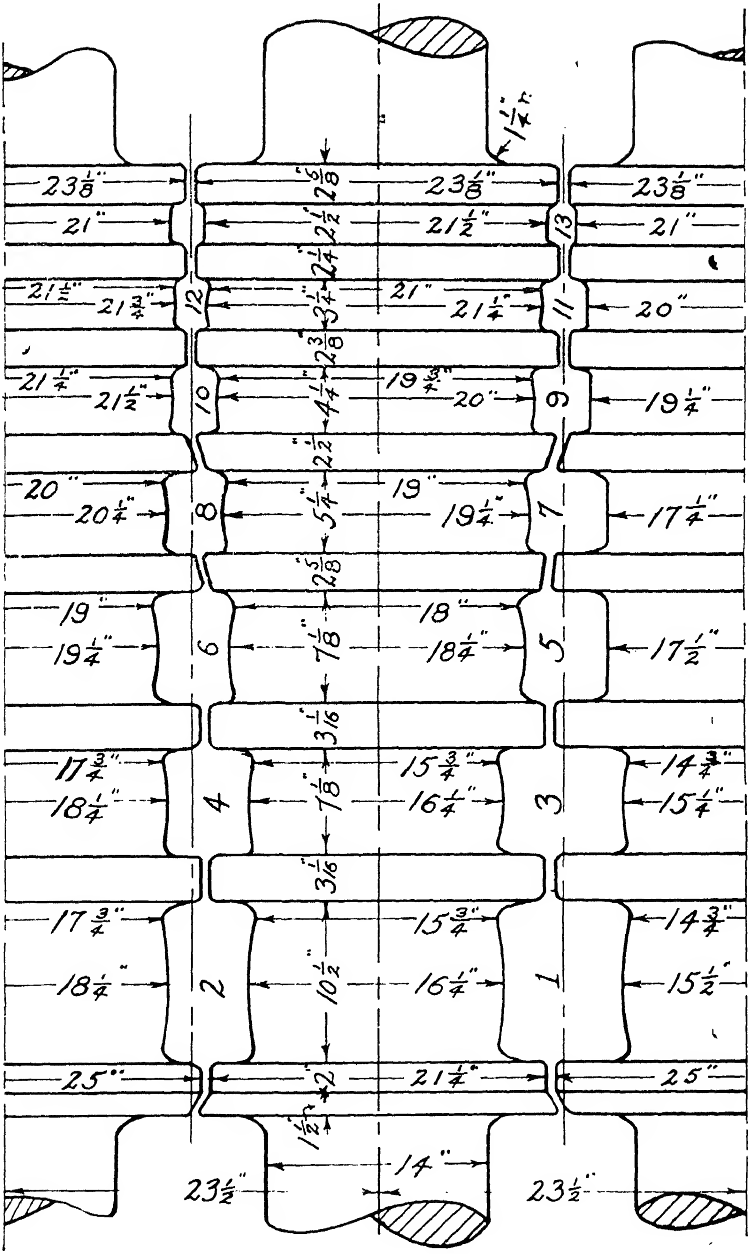
sufficiently strong for the rolling of three bars simultaneously. but the capacity of the driving unit is not sufficiently great for such operation.

Fig. 163 illustrates a set of rolls which may be termed blooming mill rolls, or, with equal right, billet mill rolls. The mill receives small ingots, which are bloomed down to a billet size. Passes are arranged one on top of the other, in spite of the narrow width of collars, because the manipulator is suitable for this small width of collars. The roll diameter is so small that it would have been impossible to arrange all the passes on the rolls if the regular three-high zig-zag method of rolling had been adopted. This fact is shown by the stresses in Table XVI. A roll of the same diameter, but of twice the length would not be strong enough. As matters are now there is some roll length to spare, (that is, "not utilized").

Rolling with one pass on top of the other necessitates differences in the working roll diameter in the same pass if the drafts are to be selected at will by the roll designer. This feature was explained on page 20 and is noticeable in Fig. 163 particularly in passes 1 and 2. The bottom roll is appreciably smaller than the middle roll, and the middle roll is very much smaller than the top roll; with the result that the bloom is curved downward as it leaves each of these passes. An attempt to correct this condition by making the bottom roll larger in pass 1 will require that the middle roll be made an equal amount smaller, if the same depth of pass is retained; which would make the difference in diameter still greater between the middle and top rolls, if the same depth of pass 2 is retained. This reasoning makes the fact clear that the only solution of such a problem is a rather unsatisfactory compromise. Unequal heating and placing the cold side of the ingot on top will counteract this tendency to curl down and bump the rollers of the delivery table.

Gothic Passes

Not many new three-high box-pass billet mills are being installed, except for alloy steels, because continuous mills are better suited for mass production, and because billet rolls for small production and small reductions are usually of the diamond or


1/4" r.
23 1/8"
2 5/8
23 1/8"
23 1/8"
21"
2 1/2"
21 1/2"
13
21"
2 1/4
21 1/2"
21 3/4"
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3 1/4"
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11
20"
2 3/8
21 1/4"
21 1/2"
10
4 1/4"
19 3/4"
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19 1/4"
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5 1/4"
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2 5/8"
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17 1/2"
3 1/16"
17 3/4"
18 1/4"
4
7 1/8"
15 3/4"
16 1/4"
3
14 3/4"
15 1/4"
3 1/16"
17 3/4"
18 1/4"
2
10 1/2"
15 3/4"
16 1/4"
1
14 3/4"
15 1/2"
25"
2"
21 1/4"
25"
1 1/2"
14"
23 1/2"
23 1/2"

Fig. 163

TABLE XVI

No. of Pass and Groove	Average Width of Groove, in.	Average Dimensions of Leaving Section: Width, in.	Height, in.	Area, sq. in.	Draft, sq. in.	Reduction, per cent	Angle of Contact, degrees	Projected Contact Length, in.	Projected Contact Area (Col. 9 × Average Width) sq. in.	Rate of Compression (1/seconds)	Temperature (Estimated) deg. F.	Compression Resistance 1000 lb./sq. in.	Total Separating Force (Col. 10 × Col. 13) 1000 lb.	Lever Arm (Estimated) (Col. 9 × 0.5) in.	Torque, not Including Roll Neck Friction, 1000 in.-lb. (Col. 14 × Col. 15)	Estimated Horsepower Including Roll Neck Friction (Speed, 50 r.p.m.)	Stress at Different Sections of Roll—1000 lb./sq. in.: Left Hand Roll Neck: Ideal Stress	Left Hand Roll Neck: Actual Stress	Right Hd. Roll Neck: Ideal Stress	Right Hd. Roll Neck: Actual Stress	Max. Stress in Roll Body: Groove Number	Max. Stress in Roll Body: Ideal Stress	Max. Stress in Roll Body: Actual Stress
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0 ..		9.5	9.5	90.3																			
1 ..	9.75	9.75	7.94	77.3	13.0	14.4	25.9	3.40	32.7	1.67	2200	9.9	324	1.70	550	1460	4.4	4.9	1.02	1.46	1B	10.35	11.5
2 ..	9.75	9.75	6.50	63.3	14.0	18.1	23.8	3.43	33.4	2.28	2190	10.7	357	1.71	611	1620	4.85	5.3	1.13	1.62	2M	9.30	10.3
3 ..	6.75	6.75	8.00	54.0	9.3	14.7	27.5	3.58	23.7	1.60	2170	10.4	247	1.79	442	1170	2.67	3.0	1.47	2.10	3B	12.05	13.6
4 ..	6.75	6.75	6.50	43.9	10.1	18.7	24.2	3.49	23.5	2.32	2140	11.3	265	1.74	461	1220	2.86	3.2	1.58	2.26	4M	10.6	12.0
5 ..	6.88	6.76	5.70	38.5	5.4	12.3	19.7	3.00	19.9	1.87	2110	11.5	230	1.50	345	914	1.92	2.1	1.94	2.77	3B	10.15	11.5
6 ..	6.88	6.88	4.90	33.7	4.8	12.5	16.9	2.70	18.4	2.22	2070	12.7	234	1.35	316	837	1.95	2.2	1.97	2.81	4M	8.44	9.5
7 ..	5.00	5.00	5.32	26.6	7.1	21.1	23.9	3.68	18.2	2.65	2030	13.6	247	1.84	454	1200	1.57	1.7	2.58	3.68	3B	8.20	9.3
8 ..	5.00	5.00	3.88	19.4	7.2	27.1	22.2	3.70	18.5	3.66	1990	15.9	295	1.35	399	1060	1.88	2.1	3.08	4.40	4 M	8.00	9.1
9 ..	4.00	4.00	3.94	15.8	3.6	18.6	19.0	3.18	12.5	2.94	1950	16.2	202	1.59	321	850	0.93	1.0	2.45	3.50	7B	5.13	5.7
10 ..	4.00	4.00	2.88	11.5	4.3	27.2	18.5	3.27	13.1	4.41	1910	19.8	259	1.63	421	1120	1.19	1.3	3.14	4.50	4M	5.13	5.8
11 ..	3.00	3.00	2.94	8.8	2.7	23.5	18.5	3.26	9.6	3.81	1870	20.2	194	1.63	316	835	0.62	0.69	2.63	3.76	7B	3.39	3.8
12 ..	3.00	3.00	2.13	6.4	2.4	27.3	15.7	2.90	8.7	5.21	1830	24.0	209	1.45	302	800	0.67	0.74	2.83	4.05	4M	2.86	3.2
13 ..	2.25	2.25	2.25	5.1	1.3	20.3	15.2	2.80	6.1	4.01	1780	24.1	147	1.40	206	545	0.29	0.32	2.18	3.12	7B	1.59	1.8

This table refers to Fig. 163, page 33.

gothic type. These latter two types are frequently used on hand operated roughing mills, particularly for rolling rounds. These shapes do not lend themselves to being carried on roller tables, and are quite suitable for small reductions. It must be remembered that, for small orders of special sections, hand mills are still very economical, and that in the rolling of these special sections, it is very convenient to start from a usually odd-sized square which can be very conveniently obtained on an old fashioned roughing mill. In Fig. 141, Vol. I, such a roll was shown; it contains gothic passes from end to end. The gothic pass is a diamond or lozenge pass with round sides. In its design the following features enter; see Fig. 164.

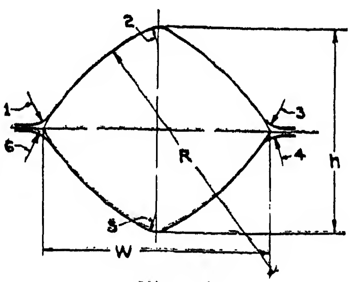


Fig. 164

(1) The ratio of sides w/h (measured to the intersection of the axes).

(2) The radius of curvature in comparison to the sides of the pass.

R

(3) The rounding or chamfer, top and bottom at (2) and (5)

(4) The fillets at (1), (3), (4) and (6).

In a general way, the ratio w/h determines the percentage reduction, because the bar is turned 90 degrees after each pass and because the width of one pass becomes the height of the next pass, while the height of one pass certainly must not exceed the width of the next pass.

If a series of gothic passes consists of geometrically similar passes, and if the width of each pass becomes the height of the

succeeding pass (considering the gothic without chamfers or fillets) then the area ratio of two succeeding passes is $(w/h)^2$. For, if w_1 and h_1 are the dimensions of one pass, and $w_2 = h_1$ and h_2 are those of the succeeding pass, the areas are $A_1 = kw_1h_1$ and $A_2 = kh_1h_2$ where k is that constant fraction which the area of the gothic has compared to the circumscribed rectangle. Hence

$$\frac{A_1}{\ } = \frac{kw_1h_1}{\ } = \frac{w_1}{\ } \times \frac{h_1}{h_2} = \frac{w_1}{h_1} \times \frac{w_1}{h_1} = \left(\frac{w_1}{h_1}\right)^2$$

because the ratio of width to height was to be constant throughout the series. A_1/A_2 equals the elongation. The reduction in per cent is, of course, equal to

$$100\left(1 - \frac{A_2}{A_1}\right) = 100\left[1 - \left(\frac{h}{w}\right)^2\right]$$

The ratio of width to height is however not kept constant throughout the series; for the gothics are almost square in the larger

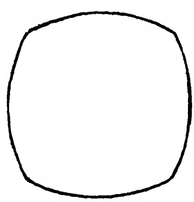


Fig. 165

sizes and are flatter or more oval in the smaller sizes, for reasons which will soon appear.

The length of the radius R is important. If R is infinitely great, the gothic becomes a diamond pass, and if R is quite small, the gothic becomes an oval. Usually the radius R lies between (the width) w and $1.5w$.

Gothics were formerly quite popular. Today they are still used, but mainly as roughing or preparatory passes for hand rounds. In other words the bar, Fig. 165 which results from being passed twice in succession with 90 degrees turn between passes through the same pass is very seldom a general pur-

pose billet, but is more often a special billet for hand rounds. The gothic pass has its limitations even for that purpose, and has been given up almost altogether for alloy steels, because it rolls the scale back into the bar instead of shedding it. This feature it has in common with all other "total enclosure" passes, which change the shape of the bar but little.

If the gothic is a preparation for a round, R is taken as small as feasible, because a small radius produces a rounder billet and therefore a better preparation for the round finishing passes.

The following practical limitations must, however, be considered. The more nearly equal w and h, and the smaller R in proportion to w, the more the gothic approaches a circle, and the harder it is to hold it from falling over. In the early passes h/w can be smaller, say 8/9 or even 9/10 because even that small ratio produces a sufficiently large projected contact area and allows safe holding. In the later passes h/w becomes smaller, say 6/7, for the purpose of producing a sufficiently large contact area, and also to furnish safety against toppling over. Table XVII contains an analysis of the roll which was shown in Fig. 141 of Vol. I. It is readily seen that the reductions are not too heavy. If they were, the great length of roll would cause very high stresses.

In spite of the comparatively light reductions with which gothic passes work, they are frequently ragged for better biting. Gothic passes are used in hand mills. In entering the bar, the roller and the rolls must jointly overcome the friction of the billet on the receiving guide. Since the upper roll of the pass is usually larger than the bottom roll, the bar is pressed against the guide, and the friction is noticeable.

The radius of the fillets in the corners can be varied within considerable limits. The value $r = 0.2h$ is commonly used. Instead of using a radius at the bottom of the groove, some roll designers prefer a straight line chamfer. This boundary was used in the roll of Fig. 141, Vol. I. By bringing the straight line chamfer farther down into the pass we reduce the danger of a fin, but we also make it somewhat harder to hold the bar in the pass. It is quite evident that the possibility of fin formation is much reduced if the chamfer (1) (4) instead of (2) (3) is used

TABLE XVII

No. of Pass and Groove	Maximum Width of Groove in.	Dimensions of Leaving Section: Maximum width, in.	Maximum Height, in.	Area, sq. in.	Draft, sq. in.	Reduction, per cent	Average Projected Contact Length, in.	Maximum Angle of Contact, degrees	Projected Contact Area (By Planimeter) sq. in.	Estimated Temperature deg. F.	Rate of Compression (1/seconds)	Compression Resistance 1000 lb./sq. in.	Total Separat'g Force (Col. 10 × Col. 13) 1000 lb.	Lever Arm (Estimated) (Col. 8 × 0.5) in.	Torque, not including Roll Neck Friction, 1000 in.-lb.	Estimated Horsepower Including Roll Neck Friction (Speed, 180 r.p.m.)	Stress at Different Sections of Roll—1000 lb./sq. in.: Left Hd. Roll N'k: Ideal Stress	Left Hd. Roll N'k: Actual Stress	Ri'ht Hd. Roll N'k: Ideal Stress	Ri'ht Hd. Roll N'k: Actual Stress	Maximum Stress in Roll Body: Groove Number	Ideal Stress	Actual Stress	Ideal Stress for C. I. Rolls	Actual Stress for C. I. Rolls
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	10.0	10.0	8.00	48.3						2200															
2	8.13	8.13	7.18	35.2	8.10	16.8	3.04	42.8	24.65	2190	8.9	12.5	309	1.52	468	4450	5.78	6.8	1.84	2.79	2	36.0	41.4	21.2	22.3
3	7.18	7.18	6.25	27.3	7.90	22.4	2.80	30.7	20.10	2180	9.0	12.7	255	1.40	356	3390	4.17	5.0	2.15	3.24	3	31.3	35.6	18.4	19.3
4	6.48	6.48	5.78	22.1	5.20	19.0	2.25	27.3	14.56	2160	9.3	13.2	192	1.12	215	2050	2.72	3.2	2.03	3.06	4	22.8	26.6	13.5	14.3
5	5.90	5.90	5.14	17.7	4.40	19.9	2.25	26.2	13.28	2140	12.4	14.3	190	1.12	213	2020	2.32	2.74	2.38	3.59	5	19.8	23.1	11.7	12.4
6	5.30	5.30	4.62	13.7	4.00	22.6	2.25	25.0	11.94	2110	16.6	15.3	182	1.12	204	1940	1.89	2.22	2.61	3.94	6	16.6	19.6	9.8	10.4
7	4.66	4.66	4.02	11.4	2.30	16.8	1.89	24.1	8.80	2080	21.8	15.8	139	0.94	131	1250	1.22	1.44	2.21	3.34	6	10.7	12.6	6.3	6.7
8	4.25	4.25	3.56	8.88	2.52	22.1	1.97	22.3	8.36	2050	28.2	16.8	141	0.98	138	1310	1.04	1.23	2.50	3.77	6	9.1	10.8	5.4	5.8
9	3.65	3.65	3.25	6.60	2.28	25.7	1.86	19.6	6.80	2010	33.1	18.4	125	0.93	116	1110	0.75	0.89	2.34	3.53	6	6.6	7.8	4.6	4.9
10	3.25	3.25	2.68	5.40	1.20	18.2	1.58	13.9	5.12	1970	24.1	19.7	101	0.79	80	760	0.50	0.59	2.00	3.02	6	4.35	5.1	3.0	3.2
11	2.88	2.88	2.40	3.80	1.60	29.6	2.19	18.2	6.30	1920	68.1	22.5	142	1.09	155	1480	0.55	0.65	2.96	4.46	6	4.8	5.7	3.4	3.6
12	2.50	2.50	2.14	3.28	0.52	13.7	1.56	16.9	3.90	1860	78.2	26.5	104	0.78	81	770	0.30	0.35	2.27	3.43	6	2.66	3.14	1.85	1.96
13	2.25	2.25	2.00	2.70	0.58	17.7	1.33	13.5	3.00	1800	70.3	29.5	88.5	0.66	58.3	555	0.18	0.21	2.19	3.30	6	1.60	1.89	1.11	1.18

This table refers to Fig. 141 of Vol. I.

in Fig. 166. The careful roll designer will make the chamfer slightly too great at the first trial and turn it down smaller if room is left for more spreading.

A section by section analysis of a gothic pass into the next gothic is shown, Fig. 167. The method of this analysis is the

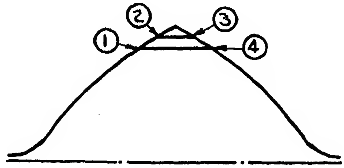


Fig. 166

same as that which was described in Vol. I, pages 103 to 107. It will be remembered from that discussion that the sections which are illustrated at the right of Fig. 167 are parts of one and the same pass. The illustration shows that the concave shape of

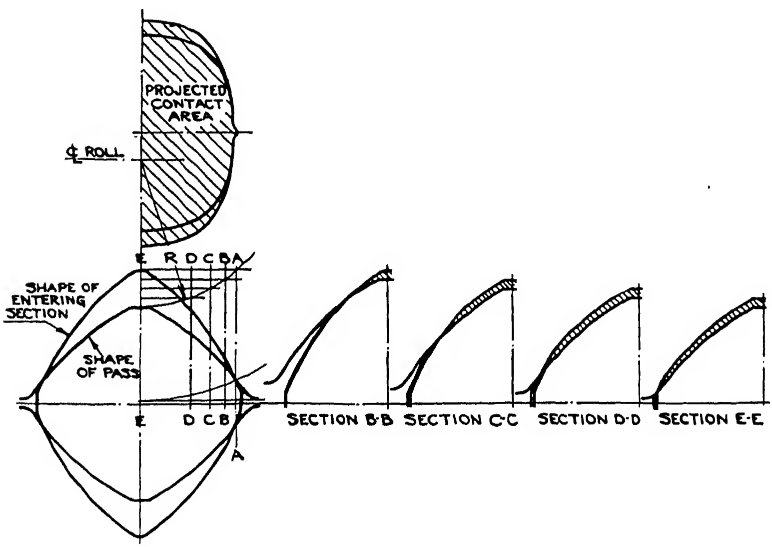


Fig. 167

the pass restricts spreading, and that the width of the pass is only slightly greater than the initial width of the bar. The small allowance for spreading allows the pass to be completely filled,

as shown in section *E-E,* which means that care must be exercised to keep each bar at as nearly uniform temperature throughout as possible.

As a rule, gothic passes are rolled zig-zag fashion; top and bottom passes are then identical. Occasionally they are arranged to roll one pass on top of the other as indicated diagrammatically in Fig. 168.

In that case the final equal sided pass cannot be obtained as simply as if the top and bottom passes are alike. If for instance, pass five is to be the last pass, then the bar would, in the mill with equal top and bottom passes, be turned 90 degrees

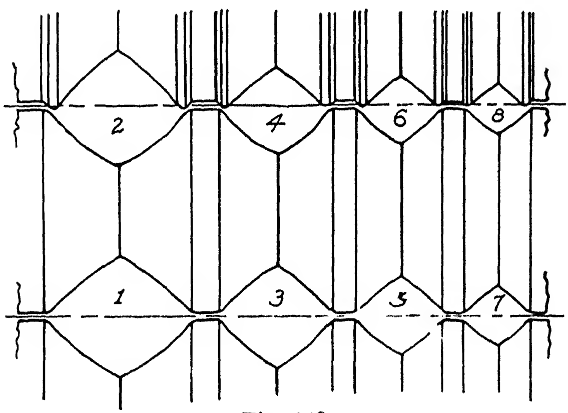


Fig. 168

and go back in the equal top groove. In the case of Fig. 168 it must go back through the larger part 4 and then go (after 90 degrees turn) through pass 5 again. The arrangement of Fig. 168 is seldom used.

Diamond Passes

Diamond passes are used as preparatory passes for square merchant bars, and also in continuous billet mills.

The methods of rolling square merchant bar are described on a later page, which narrows this section down to the use of diamonds in continuous billet mills.

As a rule, a square bloom enters the continuous billet mill

while lying flat on the approach table. The first pass is, therefore, frequently a box pass or similar pass. If the entering bloom is square, a box pass makes it rectangular, and since a square billet is needed for entering a diamond pass, another box pass or equivalent is needed. Hence we find some continuous billet mills in which two box passes or equivalent precede the diamond passes. However, a square billet lying flat will enter a diamond very well. In that case, the continuous mill can consist in its whole length of squares and diamonds.

At this point, a bit of simple reasoning on squares and

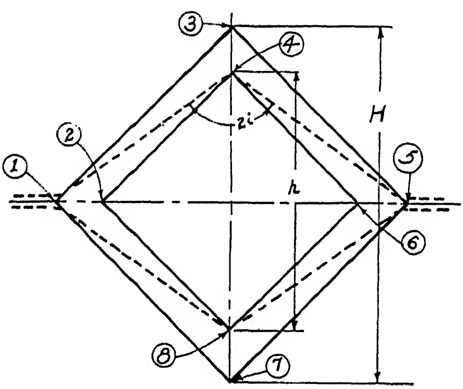


Fig. 169

diamonds will be appropriate. If the square (1) (3) (5) (7) could be entered into the square pass (2) (4) (6) (8) of Fig. 169, then a wide section would enter into a narrow pass, and wide fins would be formed, which could be made slightly smaller, but by no means avoided by fillets at the edges of the pass. The pass must, therefore, be given at least the width of the entering section, which means that it must assume the shape of the dotted line (1) (4) (5) (8), if there is no spreading whatsoever. But, since there will be spreading, the pass must be made slightly wider. It will be seen that the previously made statement is correct, namely that the reduction depends upon the ratio of the diagonals [(3) (7)] ÷ [(4) (8)] and that the angle $2i$ in Fig. 169 is a function of this ratio.

If, instead of a square being entered into a diamond, one diamond be entered into another one, as in Fig. 170, the percentage of reduction still depends upon the ratio H/h of the successive diagonals, or upon the angle $2i$ which is a function of that ratio.

The question then arises: What limits the ratio H/h (of Fig. 170) and the corresponding value of the angle $2i$, or in other words, what is the maximum possible reduction? In principle that question was answered on page 78, Vol. I.

At this point it must be remarked that the reduction is limited by the failure to bite at entrance of the bar in the first few passes. As a rule, the roll diameter is constant for all passes

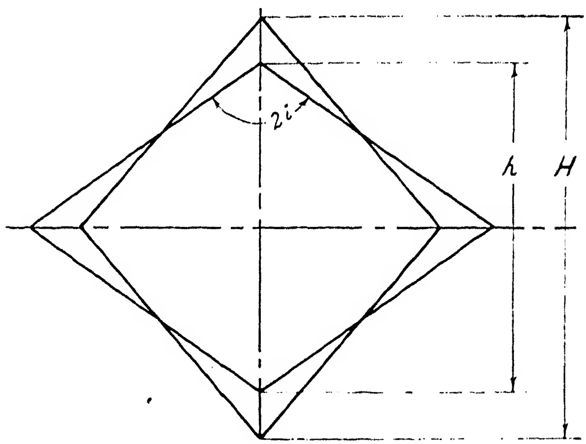
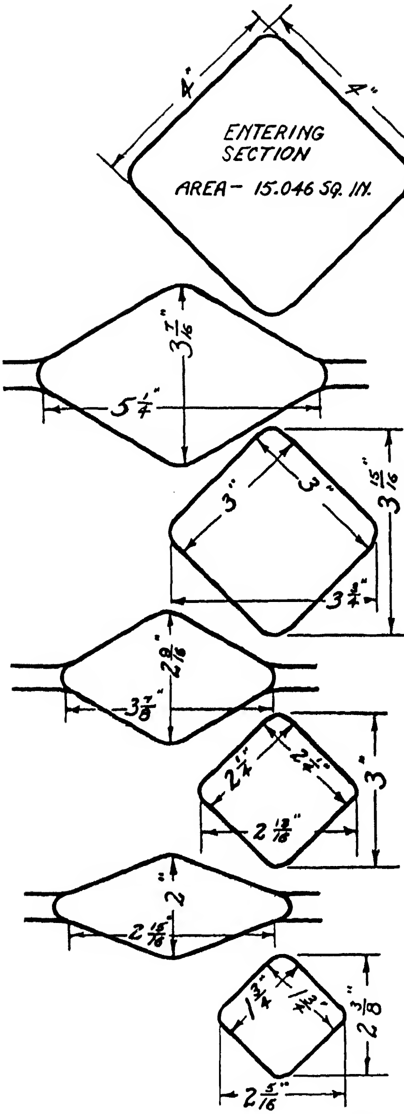


Fig. 170

of the mill; if the entrance angle is the limiting feature, reductions can become heavier as the bar becomes smaller. Some roll designers make use of this fact while others carry that reduction which is imposed by angle limitations in the first passes right through the mill without great change. For entering, the statement made on page 59 of Vol. I holds because contact begins at the apex of the pass, and is equivalent to contact between cylindrical rolls. The first pass is usually ragged.

Entering is made easier if the first two passes are box passes, or if a square billet enters a diamond. In the first case, the billet leaving the box pass is shoved into the diamond pass



PASS NO.	CROSS SECTION AREA – SQ. IN.	DRAFT – SQ. IN.	REDUCTION %	ELONGATION %	ANGLE 2i – DEGREES.	MAX. ANGLE OF CONTACT – DEGREES.
1	10.795	4.251	28.25	39.38	118	29
2	8.854	1.941	17.98	21.92	90	27
3	6.086	2.768	31.26	45.48	118	24
4	5.011	1.075	17.66	21.45	90	22
5	3.863	1.148	22.91	29.72	121	20
6	3.196	.667	17.27	20.87	90	27

Fig. 171

(if the mill is continuous), whereby ragging becomes superfluous. In the second case, the rolls exert a wedge grip, whereby the drawing-in action is increased.

Since there is an economic relation between size of bar and diameter of roll, the following relation has gradually been arrived at: The ratio of sides of two successive squares (with a diamond pass in between) lies between 1.27 and 1.33; since the areas go as the square of the sides, and the mean elongation in each of two successive passes is the square root of the product of the two successive elongations, it follows that the mean elongation per pass lies likewise between 27 and 33 per cent. No uniformity exists in the distribution of this elongation over the pair of passes. In some instances the elongation is greater for the square into the diamond, while in other cases it is greater from the diamond into the square. Figs. 171 and 172 show conclusively that both methods are used successfully.

The reduction is perceptibly influenced by chamfers and fillets. Their effect is given in Table XVIII under the heading of rolling finished squares.

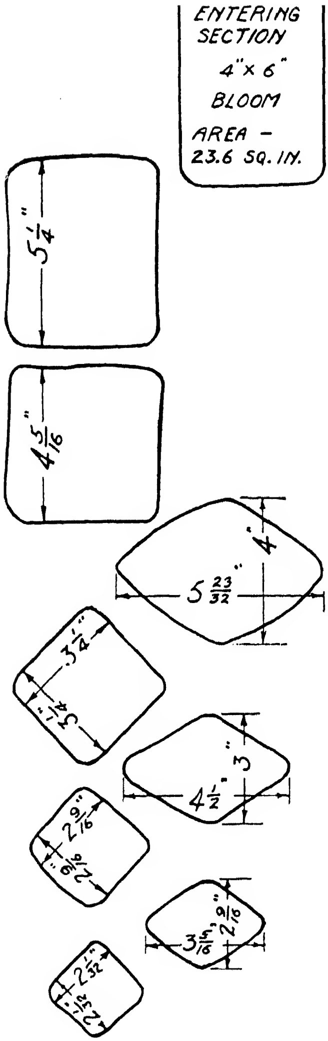
Several interesting observations can be made from a study of Figs. 171 and 172. Both are diamond-square-diamond series. The advantage of such a series is that square billets can be withdrawn at several points in the series and can be used for the rolling of various finished sections.

The second observation is that there is spreading when the diamond is compressed to a square, while there is little or no spreading, when the square is compressed to a diamond. Both facts agree with the effects of shape of projected contact area and with the ratio of projected contact length to thickness of bar.

The third observation is that the spreading is not alike in the two sets of passes. Difference in bar material, roughness of roll and in temperature distribution in the bar will easily account for this fact.

Fig. 173 illustrates a diamond-diamond series which is used in breaking down a square billet to a section convenient as a starting point for a specific smaller section.

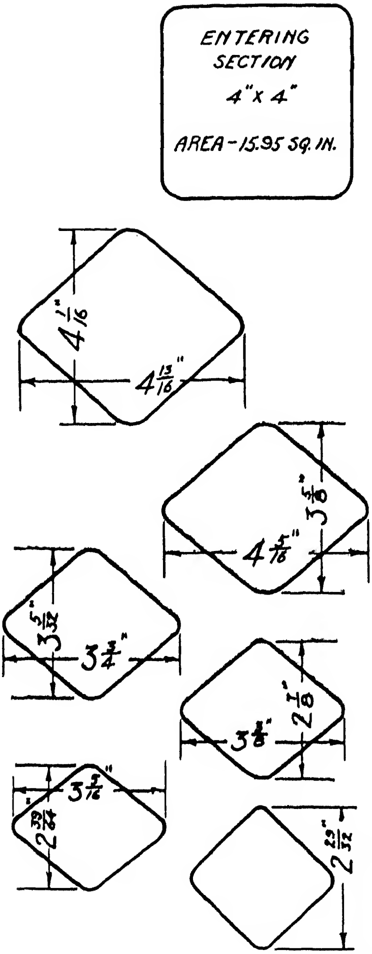
This illustration and tabulation teach that information on roll passes must frequently be taken with suspicion. The data were taken from the exhibition board of a prominent steel corpo



PASS NO.	CROSS SECTION AREA - SQ. IN.	DRAFT - SQ. IN.	REDUCTION - %	ELONGATION - %	ANGLE 2i - DEGREES	MAXIMUM ANGLE OF CONTACT - DEGREES
1	21.12	2.51	10.44	12.0		24
2	17.95	3.17	15.00	17.8		25
3	14.63	3.31	18.50	22.9	115	24
4	10.42	4.29	28.50	40	87	29
5	8.12	2.30	22.05	28.1	119	30
6	6.23	1.89	23.30	30.5	90	28
7	5.08	1.15	18.50	22.9	110	20
8	4.07	1.01	19.90	25.0	87	20

Fig. 172

ration and very probably do not represent sections from actually rolled semi-finished billets. The chances are that they were made from the templets (used in turning the roll) and that the radii at the ends of the long (horizontal) diagonals were put



PASS NO.	CROSS SECTION AREA - SQ. IN.	DRAFT - SQ. IN.	REDUCTION - %	ELONGATION - %	ANGLE 2i - DEGREES
1	10.99	4.96	31.0	46	99.3
2	8.94	2.05	18.7	23	99.6
3	6.84	2.10	23.5	31	98.2
4	5.60	1.24	18.1	22	99.1
5	5.00	0.60	10.7	12	106.1
6	4.67	0.33	6.6	7	91.9

Fig. 173

in by the judgment of the machinist who finished the sections.

This assumption would account for the wide variation of reduction for practically the same angle $2i$.

Rolls for Finished Sq

While large semifinished squares (billets and blooms) are

very common sections, large finished squares are comparatively rare. For that reason they are rolled on hand mills.

Two methods are used. In one method, each pass is a roughing pass and also a finishing pass. The angle $2i$ in Fig. 174 is only a very small amount larger than 90 degrees, namely 91-1/3 degrees for small squares, 91 degrees for medium squares,

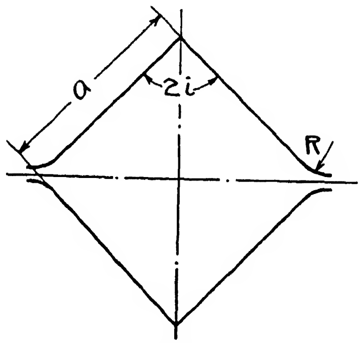


Fig. 174

and 90-2/3 degrees for large squares. The ratio of areas of two successive diamonds is determined by the requirements of safe entering without fin formation.

For squares of 3-inch to 4-inch side, steps of 3/16 inch are recommended; for 2-inch to 3-inch squares steps of ⅛ inch are usual, while 5/64-inch steps are used for 1-inch to 2-inch squares (although the latter size is commonly rolled on guide mills).

Fig. 175, which was drawn for a 3½-inch square, shows conclusively that these steps must produce a slight overfill which is rolled back into the bar in the succeeding pass. Degeneration of the overfill into a fin is prevented by rounding the edges of the pass quite liberally. The radius r of the fillet varies between $0.35a$ and $1.0a$ where a equals the side of the diamond. In Fig. 175 the radius r equals $\frac{1}{2}a$.

Hand rolling in grooves of this type has the advantage that each pass can be used as a roughing pass, a leader, and also a finishing pass. To be finished in any one given pass, the bar is passed through it twice (or three times if the arrangement of

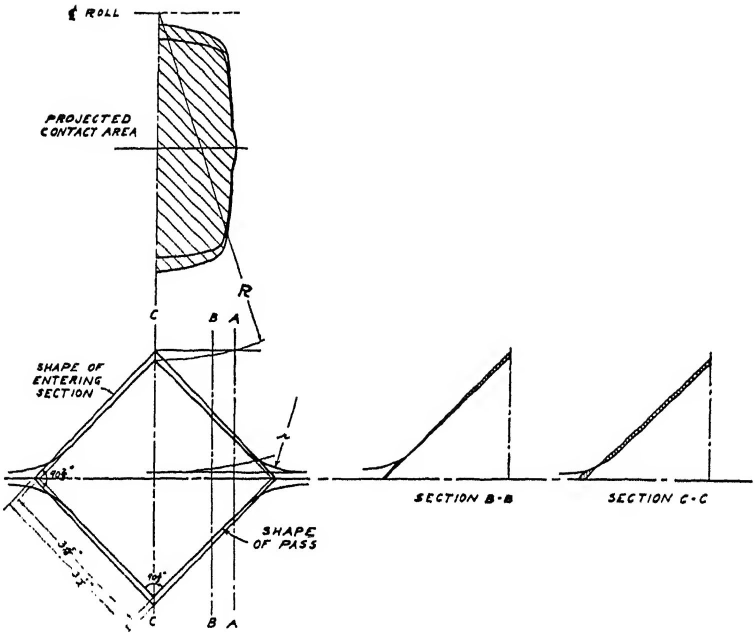


Fig. 175

the mill requires it) with 90-degree turns between passes. The finished hot bar is slightly octagon as shown in an exaggerated manner by Fig. 176. However, the bar, while cooling, contracts into a perfect square because the corners are colder and do not contract as much as the rest. In other words: The distance (1)

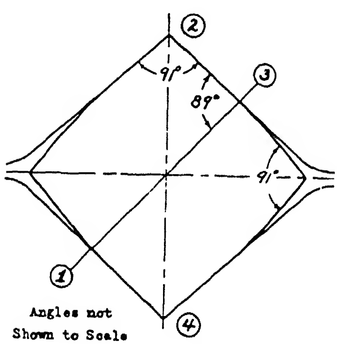


Fig. 176

(3) of Fig. 176 contracts more than the distance (2) (4), in proportion to their lengths.

The advantages of this type of hand rolling of squares are bought at the expense of several disadvantages. Only short billets can be used. The reduction is very small (in Fig. 175 the reduction is 8.4 per cent; 10 per cent is the maximum). If long lengths were used, the large number of passes would cause excessive cooling of the bar. Short billets and low rolling speeds are furthermore necessitated by the holding of the bar by tongs. If one pass is adjusted, it throws all other passes out of adjustment.

The advantages and disadvantages assign a definite field to this method of rolling squares; it is the field of small orders of varied sizes of short lengths of squares between 3 inches and 5 inches.

If the individual orders become larger, it pays to provide a separate finishing stand. In that case, reductions in the roughing roll can be greater than in the former case. The angle $2i$ of Fig. 174 may, for the here discussed method of rolling, be made as large as 100 degrees, while the finishing stand has grooves such as Fig. 174. Fig. 177 shows a series of passes with $2i = 100$ degrees. The first passes are not exactly diamond shaped, but approach a gothic. The average reduction is 19 per cent.

If still greater reductions are desired, guides must be used. The following angles $2i$ are then frequently used:

Size of square	Angle $2i$, degrees
Below ½ inch	112
½ inch to 1 inch	108
1 inch to 1½ inches	105
Above 1½ inches	102

Another way of expressing the rule is the following: the difference between horizontal and vertical diagonals is made equal to one-quarter of the side of the square for small square sections, and equal to one-fifth of that side for larger sections.

The increase of angle for the small sections has two causes. Guides have a certain amount of play and wear. For small sec-

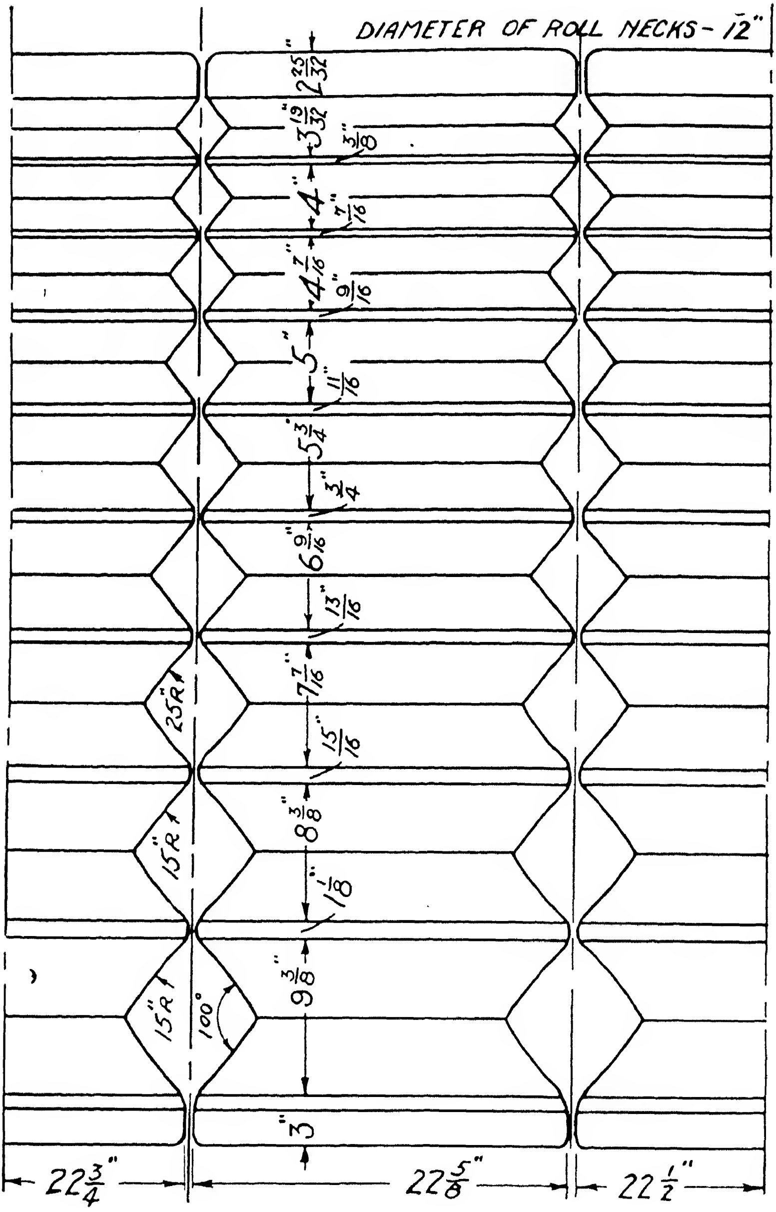

DIAMETER OF ROLL NECKS - 12"
2 25/32
3 19/32"
3/8"
4"
7/16"
4 7/16"
9/16"
5"
11/16"
5 3/4"
3/4"
6 9/16"
13/16"
7 7/16"
15/16"
8 3/8"
1 1/8"
9 3/8"
3"
25"R
15"R
15"R
100°
22 3/4"
22 5/8"
22 1/2"

Fig. 177

tions, that wear and play is a greater fraction of the total depth, which means that the guiding is less certain than it is for a larger section. That drawback is counteracted by making the small section more oblong or lozenge shape than the larger sections.

The larger angle $2i$ used with the small sections produces greater percentage reduction. This is desirable, because small sections cool rapidly, and is permissible because small sections are put on comparatively large mills (considering ratio of roll diameter to depth of pass).

Finally, small sections usually spread more, because they have a cool crust.

Sections of more than 2-inch side of square are at present not rolled by guides in any quantities.

The effect of the angle $2i$ upon reduction will become clear from the following tabulation (Table No. XVIII) which refers to Fig. 178.

TABLE XVIII

	Width of Pass Entering Width		Width of Pass Greater than Entering Width — Passes with Sharp Corners			Passes with Chamfers and Fillets	
Angle $2i$, degrees 1	Ratio of Diagonals 2	Per cent Reduction 3	Width of Pass : Entering Width 4	Ratio of Diagonals 5	Per cent Reduction 6	Width of Pass ÷ Entering Width 7	Per cent Reduction 8
91	0.983	3.5	1.00	0.983	3.5	1.10	20.0
92	0.966	6.8	1.01	0.966	5.0	1.11	20.9
93	0.949	10.0	1.02	0.949	6.5	1.12	22.1
94	0.932	13.0	1.03	0.932	7.8	1.13	23.5
95	0.916	16.0	1.04	0.916	9.4	1.14	24.8
96	0.900	19.0	1.05	0.900	11.0	1.16	25.9
98	0.869	24.5	1.08	0.869	12.5	1.19	26.6
100	0.839	29.9	1.11	0.839	13.8	1.21	28.0
102	0.810	34.5	1.14	0.810	15.0	1.26	29.3
104	0.781	39.0	1.17	0.781	16.5	1.28	30.4
106	0.754	43.2	1.20	0.754	18.3	1.32	32.1
108	0.726	47.1	1.23	0.726	20.3	1.35	33.8
110	0.700	51.0	1.26	0.700	22.7	1.38	35.3
112	0.674	54.6	1.29	0.674	24.8	1.42	38.0

Pas	Draft, inches (for mild steel, of less than 0.25 per cent C.)
First and second	3/16-3/8
Intermediate	3/16-5/16
Leader	5/64-5/32
Finishing	1/32-3/64

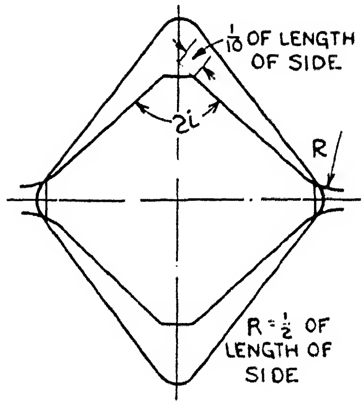


Fig. 178

Finished squares are required to have sharp corners. For that reason, chamfers and fillets will not do, in the finishing stand, and must be very small in the leader.

Small squares are rolled continuously by one of the quick-reduction series, which are discussed in a separate chapter.

CHAPTER II

ROLLING OF FLAT SECTIONS

Rolls for Slabbing Mills

Slabs are semifinished material and are converted into plates, strip and skelp. They are rolled on mills having both horizontal and vertical rolls (the so-called universal slabbing mill) or on high-lift blooming mills.

Universal slabbing mills require no roll design at all, and slabbing-blooming mills only a very small amount. The latter statement is borne out by a glance at Fig. 179 which represents one of the two rolls of a slabbing-blooming mill. It will readily

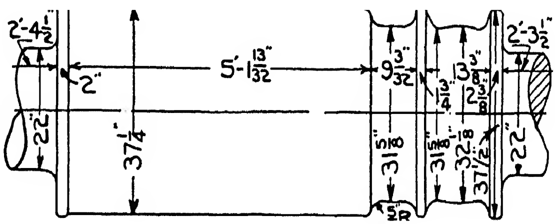


Fig. 179

be observed that there are only three passes, namely the bullhead and two edging passes.

The engineers determine the ratio of roll length to roll diameter (in this case equal to 2.4) and the width of the slab to be rolled. The only question which may arise is this: How wide shall the edging passes be? In the answer a great deal of latitude can be allowed. As a rule, we can allow three passes in the bullhead before edging, then edge, have three more passes in the bullhead, edge again, and give three final passes in the bullhead. In this manner, a sufficient reduction can be ob-

tained, and a 27-inch slab ingot can be rolled down to about 6-inch thickness.

The width of the edging grooves is determined by the drafts in the bullhead. As a rule these widths need not be determined with any great accuracy, because the roller can help himself very easily by varying the drafts in the bullhead.

Rolls for Rolling Flats

The first step which the roll designer must take in the design of rolls for rolling flats is to decide upon an initial square section which will produce a flat of the required dimensions. In order to reach this decision, he must consider the following factors; ratio of width to thickness of finished flat, ratio of total free spreading to total reduction in thickness, and the amount of edging or side work required to protect the edges of the flat from cracking.

Referring to Fig. 180, the following relations exist: Let a and b be the dimensions of the finished flat, and let k represent the ratio of total spreading to total draft. Also let r, r' r'',

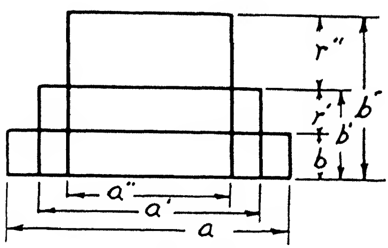


Fig. 180

etc., represent the drafts in successive passes. Then if the total draft in inches is represented by R,

$$R = \Sigma r = \text{sum of all drafts.}$$

Furthermore,

$$a' = a - kr'$$
$$a'' = a' - kr'' = a - k\,(r' + r'')$$
$$k\,\Sigma\, r = a - k$$

$$b' = b + r'$$
$$b'' = b' + r'' = b + r' +$$
$$b_{n} = b + \Sigma\, r = b + R$$

Then, a_n and b_n will be the side of a square, when

or when

$$\frac{a - b}{1 + k}$$

and the side of the square will be $b + R$, which equals

$$b = \frac{a - b}{1 + k}$$

The value of k in this equation is determined by the various factors which affect spreading, as discussed on pages 82 to 100 of Vol. I, and is known by experienced roll designers to vary commonly between 0.30 and 0.35, and to rise as high as 0.5 under certain conditions.* The above reasoning, however, does not take into consideration the edging passes which may be required, the result of which is partially to counteract the effect of the previous spreading. This statement applies equally to edging which is done in grooved passes of horizontal rolls, or between vertical edging rolls, or to the suppression of spreading by side work in tongue and groove passes. Consequently, the effect of edging is equivalent to reducing the value of k in the above equation.

Depending upon the amount of work done in edging passes, or of side work done in tongue and groove passes, k varies between 0.2 and 0.3.

The above-given method for finding the initial square is a quick approximation. Usually, the roll designer starts from the flat and works back, step by step, until he arrives at a commercial square or rectangular billet. He can then take care of a variation of the spreading factor, and of the effects of edging.

Flats are rolled:

1. In continuous mills with edging rolls between main stands,

*This is based on the Geuze theory. Strictly, it would be more correct to use the formula given on page 87 of Vol. I, but for convenience the simpler theory was used here.

2. Between stepped rolls (flat and edging),
3. Flat in tongue and groove rolls,
4. On the diagonal, (similar to the rolling of squares).

For large orders or stock production of flats of soft steel and medium steel, the continuous mill is satisfactory. It calls for no roll changes (except those due to wear) and for no roll design, except distribution of draft between the various stands. The edges obtained on these flats are, however, not as sharp as those obtained in tongue and groove rolling.

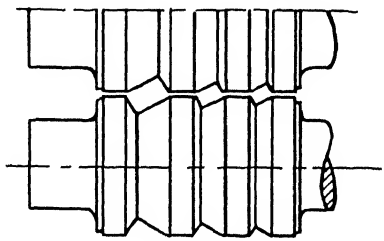


Fig. 181

Method No. 4 might, at first thought, appear to be the best all around method, because the steel is compressed (receives work) on all four sides. It can, however, be used only on those flats for which the ratio of sides is between 2 and 1. A roll showing finished flats of this description is given in Fig. 181. The

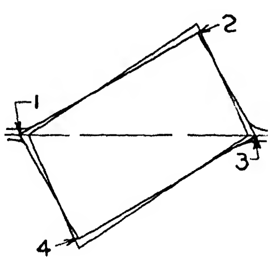


Fig. 182

leader is not rectangular. Both finished pass and leader are shown in Fig. 182. If flats of more than 2:1 side ratio are rolled in this manner, they curl up like a cork screw. Two conflicting force actions occur, see Fig. 183. When the delivered bar drops on the table, its weight causes it to turn clockwise about point

(4), which fact puts a slight twist into the bar, because it becomes too cold to reflatten itself. On the other hand, points (1) and (3) are delivered with higher velocity on account of the difference of roll diameters, than points (2) and (4). Since the pressure against the long sides is greater than that against the short sides, the result is a counter-clockwise corkscrew motion, which twists a weak long flat around quite merrily. If the flat is more nearly square, as shown in Fig. 182, points (1) and (4) —or (2) and (3)—do not lie directly opposite each other, and the twisting action is very much smaller; furthermore, the bar is stiffer against twisting. Even then it is frequently necessary to keep the bar from twisting by using delivery guides with rollers.

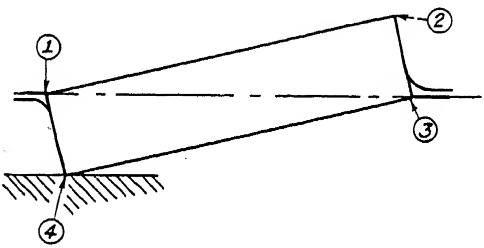


Fig. 183

The method of diagonal rolling is commonly used for tool steel, which finishes rather cold and is of the right ratio of sides.

Where no continuous mill is available, the flat and edging method (2) or the tongue and groove method (3) is used. In the flat and edging method, stepped rolls are used, such as shown in Fig. 14, Vol. I. The step and edge, or flat and edge method is particularly useful for flats of intermediate width. For very wide flats it fails, because wide flats buckle while being edged. For wide flats, tongue and groove rolling (with sidework caused by suppressed spreading) is the only available method, in the absence of a continuous mill with vertical edging rolls.

It might appear as if the stepped roll calls for no roll design. Nevertheless a certain amount of reasoning is required in connection with the layout of stepped rolls. The drafts, width of

flat, roll length, and roll diameter must be so harmonized that the stress in the roll is of the correct value. These relations were explained in Vol. I, pages 20 to 41. Also, the steps must be adapted to the thickness of the entering bar and to the thickness of the finished bar. The following relations exist, as shown in Fig. 184.

$$h_1 = h_2 + (D_2 - D_1)$$
$$h_2 = h_3 + (D_3 - D_2)$$
$$\frac{h_1}{h_2} = \frac{h_2 + (D_2 - D_1)}{h_2} = 1 + \frac{D_2 - D_1}{h_2}$$

Since no finishing work is done between the stepped rolls, reductions can be fairly heavy, say 35 per cent, which means

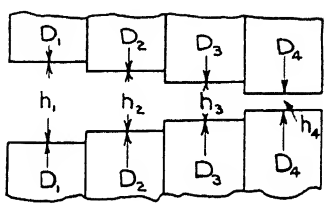


Fig. 184

elongation of 1.54. The thickness ratio $h_1 \div h_2$ which corresponds to these values of reduction and elongation varies with the ratio of draft to width and thickness. Referring again to Fig. 180, the following relations are found: The elongation in one pass is equal to $a'b' \div ab$, which equals $a' \div a \times$ thickness ratio. But

$$\frac{a'}{a} = \frac{a + kr'}{a} = 1 + \frac{kr'}{a}$$

Then since $r' = D_2 - D_1$, from Fig. 184,

$$\frac{a'}{a} = 1 + \frac{k(D_2 - D_1)}{a}.$$

The resulting equation, therefore, is:

$$\frac{\text{elongation}}{\text{thickness ratio}} = \frac{a'b'}{ab \div \frac{b'}{b}} = 1 + \frac{k(D_2 - D_1)}{a}$$

TABLE XIX

Values of Thickness Ratio for Various Values of Spreading Factor, k, and of Ratio Draft/Width
(Spreading factor, k = spreading ÷ draft.)

	$k = 0.20$							$k = 0.25$					$k = 0.30$			
Draft/Final Width....	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.2	0.3	0.4	0.5	0.6	0.3	0.4	0.5	0.6
Elongation																
1.2	1.21	1.22	1.24	1.28	1.30	1.33	1.36	1.26	1.30	1.33	1.37	1.41	1.32	1.36	1.41	1.46
1.3	1.31	1.33	1.34	1.38	1.41	1.44	1.48	1.37	1.41	1.45	1.49	1.53	1.43	1.48	1.53	1.59
1.4	1.41	1.43	1.44	1.49	1.52	1.56	1.59	1.47	1.51	1.56	1.60	1.65	1.54	1.59	1.65	1.71
1.5	1.52	1.53	1.55	1.60	1.63	1.67	1.70	1.58	1.62	1.67	1.72	1.77	1.65	1.70	1.76	1.83
1.6	1.62	1.63	1.65	1.70	1.74	1.78	1.82	1.69	1.73	1.78	1.83	1.88	1.76	1.82	1.88	1.95
1.7	1.72	1.74	1.75	1.81	1.85	1.89	1.93	1.79	1.84	1.89	1.94	2.00	1.87	1.93	2.00	2.07

By means of this equation, the value of the thickness ratio can be calculated for given values of draft/width, elongation, and spreading factor. For the sake of convenience in making rapid approximations, values of the thickness ratio have been calculated for various values of these factors, and are given in Table XIX. For example, let us suppose that a flat 3 inches by ⅞ inch is to be rolled from a given pass, and that an elongation of 1.4 is desired in that pass. Let us assume that the value of k is 0.20 for the series of passes of which the pass considered is a part. If the draft in this pass is taken as approximately ⅜ inch, the ratio of draft/width is thereby determined as being approximately 0.125. By consulting the table, we find that the thickness ratio required to produce this result is about 1.43, which would make the entering thickness 1.43 $\times$ 0.875, or 1.25 inches. The width of the entering bar would then be 3 — 0.2 $\times$ 0.375 = 2.925 inches. From the values in this table, it follows that for the majority of cases the draft is from 30 per cent to 60 per cent of the thickness of the bar. Since this is so, the range of up and down adjustment of the stepped roll is limited. While the drafts (from step to step) remain the same for any adjustment, the elongations vary.

The permissible draft in any one pass of stepped rolls of course varies. A common practice is illustrated by the following figures, which apply particularly to narrow flats. For wider flats it is common to limit the draft to 30 per cent of the initial height in the roughing passes, and to the same values as below in the leader and finishing passes.

For instance, to roll a flat 1¾ inches x 5/16-inch from a square 1½ inches x 1½ inches, the following passes and reductions might be used:

Pass	Thickness, in.	W lth.	Draft, in.	Spreading, in.	Spreading facto
6—Finishing	0.3125	1. 5	0.0475	0.01	0.20
5—Leader	0.360	'4	0.165	0.04	0.25
4—	0.525	'0	0.300	0.10	0.33
3—Edging	0.825	.60	0.170	0.05	0.33
2—	0.775	.77	0.350	0.12	0.34
1—	1.125	.65	0.375	0.15	0.40
0—	1.50	.50	(Initial square section)		

In stepped rolls the width of each step equals the width of the widest flat (to be rolled on the mill) plus 2 inches or even more. A separate finishing stand must, of course, be provided. In the grooved edging passes of stepped rolls the draft lies between 5 and 10 per cent of the entering height. The lower value is used for thin flats. The draft must be even smaller if edging is done between plain, cylindrical passes. Such edging grooves are

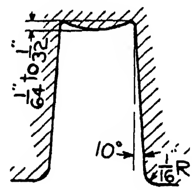


Fig. 185

commonly made as shown in Fig. 185. The purpose of the belly is to produce a sharp cornered flat in the finishing stand. If sharp corners are not desired, the belly can be omitted. The flats must fit snugly in the groove, for proper guiding and support.

It should be mentioned at this point that it is desirable, whenever possible, to edge flat sections immediately before the finishing pass; and that edging of flat sections is very rarely done between plain cylindrical rolls. The practice of rolling flats in tongue and groove passes is avoided by many roll designers for the following reasons: In tongue and groove passes, no opportunity is given for scale to drop off from the bar, with the result that it is very difficult, particularly in the rolling of alloy steel, to obtain a clean product with this method of rolling. The tongue and groove method also requires a separate set of rolls for each different width and thickness of flat which is to be rolled, and the numerous small orders of various sizes which are required by modern practice make the method impractical in many cases. The only field in which the tongue and groove method is extensively used at present is the rolling of sheet and tin bar. Even for that material it has largely been replaced by continuous mills with separate edging rolls.

Flats departing but little from a square (such as are rolled for tool steel) are occasionally rolled between cylindrical rolls from a leader which is a fluted square, as shown in Fig. 186, and which enters the rolls flat (*not* on the diagonal). The depression of the sides of the square is about 1/32 inch. If b and c are to be the sides of the flat, the side of the square from which the flat can be rolled is approximately ½ $(b + c)$.

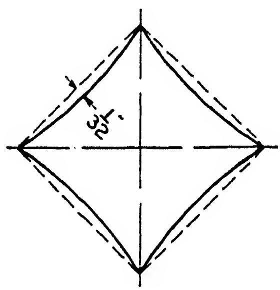


Fig. 186

Where close adherence to dimensions is required, and where uniformly sharp edges are demanded (as for instance in preparation for cold drawing) tongue and groove rolling is practiced, at least in the finishing stand.

As previously stated, tongue and groove rolling is also used for thin, wide flats, such as sheet bars and hoops.

Sheet Bars

Among the semifinished flats are sheet bars and tin plate bars. They are usually 8 inches wide and range in thickness from ¼-inch to ¾-inch, depending upon the gage of sheet which is to be made from them. Fig. 187 shows the direction of rolling for the bar. It also shows that, after the bar has been sheared, the sheet is rolled at right angles to the original direction of rolling.

In recent years, the rolling of strip sheets has reduced the

demand for sheet bar; however, sheet bar passes are so instructive that they will be discussed here.

A set of roll passes for rolling 8-inch sheet bar is shown in Fig. 188. These rolls are placed in two stands, as indicated. In this set of passes, it will be noticed that the edging pass immediately follows the first pass. The purpose of this early edging pass

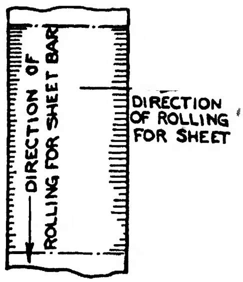


Fig. 187

is not only to protect the edges of the bar, but primarily to crack off the scale, thereby allowing a cleaner sheet bar to be produced. The values in Table XX show the dimensions of the bar in each pass, for the rolling of light weight sheet bars.

It will be noted that in the flat passes the allowed spread-

TABLE XX

(Referring to Fig. 188)

Pass No.	Thickness, in.	Width, in.	Area, sq. in.	Reduction in Area, sq. in.	Reduction in Area, per cent	Draft, in.	Actual Spreading, in.	Natural Spreading, if Unrestrained, in.
	2.375	8.75	20.00					
2	7.75	2.50	17.80	2.20	11.0	1.00	0.125	0.113
3	1.506	7.88	11.25	6.55	36.8	0.994	0.130	0.464
4	1.03	8.00	7.86	3.39	30.1	0.476	0.120	0.261
5	0.719	8.10	5.60	2.26	30.0	0.311	0.100	0.202
6	0.500	8.18	4.09	1.51	27.0	0.219	0.077	0.070

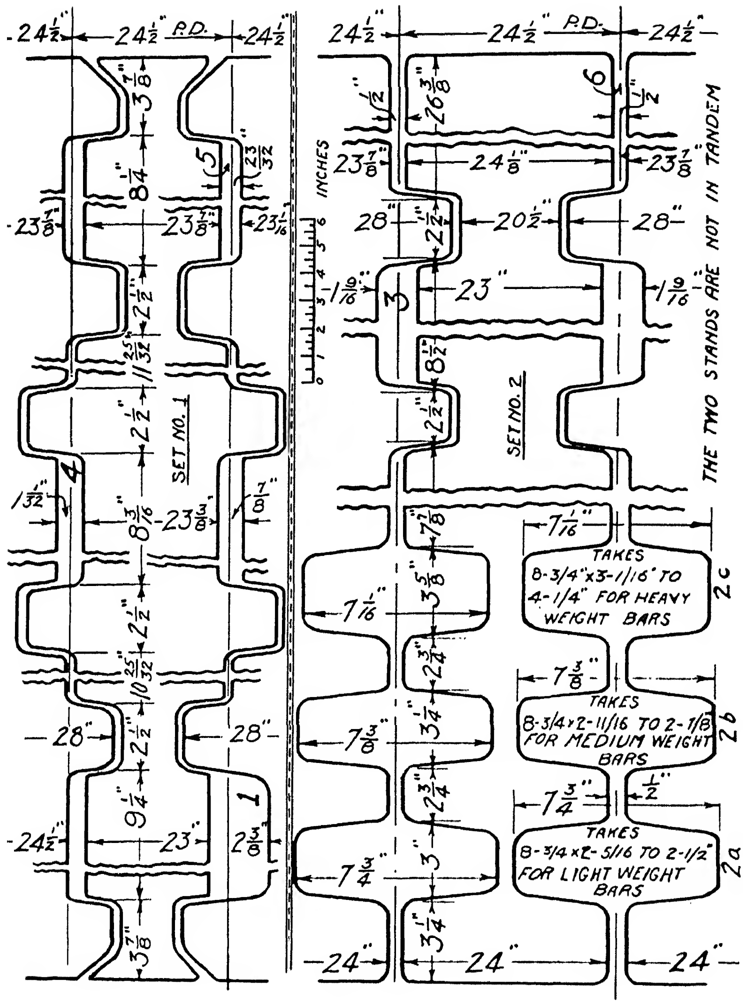


Fig. 188

ing is less than the natural spreading, indicating that side-work is obtained by the suppression of spreading in passes 3, 4 and 5.

As previously mentioned, difficulties arise if material is continually compressed in the same direction without edging or turning. Fine hair cracks appear at the edges as indicated in Fig. 187. In the finished sheets this feature is especially

objectionable because the cracks become quite deep (that is to say: long in the direction of the sheet, which is rolled at right angles to the direction of rolling of the bar) and produce much waste material. It has also been previously stated that these cracks are avoided if the lateral spreading is limited to a value considerably smaller than that which would correspond to the natural spreading in the open pass. This limitation of spreading is accomplished by side work in closed passes, as illustrated in Fig. 188 and Table XX. The problem of how much lateral spreading to allow and how much to chamfer around the corners was discussed on pages 139 to 141 of Vol. I.

Fig. 189 illustrates a set of roll passes in which a 6-inch by 6-inch billet is reduced to 10-inch tin plate bars. This illustration shows clearly how sidework can be obtained in the late roughing passes by designing the earlier roughing passes so as to make the section thicker at the edges than in the center. The use of chamfers and fillets to prevent fin formation is also shown in these passes. The values of actual spreading in these passes and of natural spreading if unrestrained, together with the dimensions of the bar, are given in Table XXI. It will be noted that there is no edging pass, and that all protection of the edges is accomplished by the suppression of spreading. It should be observed, in order to avoid being misled by the values of the spreading which are given in Table XXI, that spreading is not suppressed in all passes; in fact spreading is encouraged in certain passes in order to produce the 10-inch tin bar from a billet which is only 6 inches wide. For instance, in pass 5, the allowed spreading is 0.75, which means that, if the pass fills, the actual spreading is twice the average draft. The reason for this is that the center of the bar receives very little compression in pass 5, the greatest reduction in that pass occurring at the sides of the bar. This is substantially a prevention of elongation which, as was discussed in Vol. I, produces much spreading. It becomes apparent from a study of the valves of the spreading in Table XXI that spreading is suppressed— that is, protection of the edges is provided—only in Pass No. 4, of this set of passes. It is questionable whether this provides a

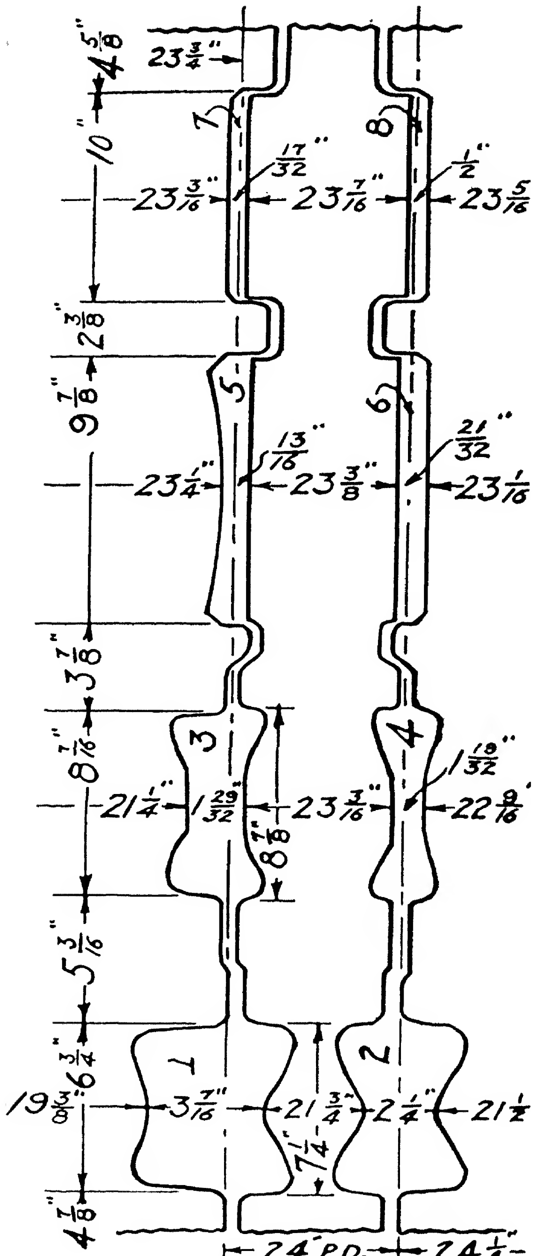


Fig. 189

sufficient amount of sidework to protect the edges of the bar against cracking. If not, the only alternative is to redesign the passes, using a larger square or a wider rectangle as a starting section.

TABLE XXI
(Referring to Fig. 189)

Pass No.	Average Thickness, in.	Width, in.	Area, sq. in.	Reduction in Area, sq. in.	Reduction in Area, per cent	Average Draft, in.	Spreading, in.	Natural Spreading, if Unrestrained, in.†
0	6.00	6.00	35.3	...	...	....	...	....
1	4.61	6.88	31.7	3.6	10.2	1.39	0.88	0.31
2	3.78	7.12	26.9	4.8	15.1	0.83	0.32	0.19
3	2.43	8.40	20.4	6.5	24.2	2.35	1.28	0.48
4	1.40	8.75	12.2	8.2	40.1	1.03	0.35	0.48
5*	1.06	9.50	10.1	2.1	17.2	0.34	0.75	0.17
6	0.656	9.80	6.29	3.81	37.7	0.40	0.30	0.15
7	0.531	9.90	5.20	1.09	17.4	0.125	0.10	0.08
8	0.500	10.0	4.97	0.23	4.4	0.031	0.10	0.013

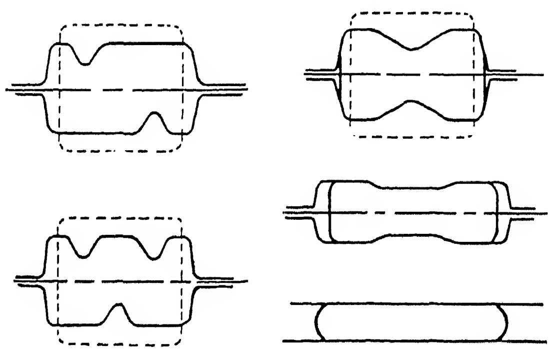
*Width of groove No. 5 = 9.88 inches.
†Calculated for rectangular bar of same average thickness.

In any event, the lack of protection of the edges of the bar in these passes (referring to Fig. 189) signifies that only mild steel of high quality could be rolled successfully in these passes. Steels containing more than the usual amounts of sulphur or phosphorus, or small amounts of copper, crack very easily at the edges, and need more edging or side work than is provided in these passes.

These passes of Fig. 189 illustrate one method of obtaining abundant spreading by reducing the section nonuniformly. Other methods which accomplish the same purposes are shown in Fig. 190. Much spreading is obtained in these passes, not only because of the nonuniform reduction, but also because the shape of the rolls produces lateral tension in the bar.

In addition to the problems already mentioned, there are other points of interest which arise in the rolling of sheet bar. They are well illustrated by the section by section analysis of three sheet bar passes, shown in Figs. 191-3. In all three illustrations the numbers of the sections correspond to those

marked on the periphery of the roll. Turning to the entering section on the extreme right of Fig. 193, we notice that the lower surface of the bar is wider than the bottom of the groove. Consequently, the bar touches the top roll with its entire upper surface, while it touches the bottom roll, only in the corners of the groove. Strictly speaking, this is true only when the bar first enters the roll. As soon as the entering section of the bar has passed the center line of the rolls it touches the bottom rolls at the corners of the groove without at the same time touching the top roll. The stiffness of the bar (in addition to the reaction from a guide box if such is used) then takes up the upward thrust. This action shifts



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the center line between *A-A* and section 1 and 2, Fig. 193, and shifts the roll outline to *B-B* for section 1 and to *C-C* for section 2. This discrepancy, however, does not materially affect the present analysis. Bearing in mind that plastic material flows in the direction of least resistance, it is seen that the whole section may bend as indicated in Fig. 194, or that there may be a local deformation as indicated in Fig. 195, each horizontal line *h-h* changing to a curved line *c-h*. Bending of the bar, as shown in Fig. 194 would undoubtedly occur if the entire length of the bar were subjected to the described action. The application of the forces, however, is confined to the short distance from section 2 to section 4 of Fig. 193; therefore the local deformation illustrated in Fig. 195 is more likely to be the result of the action.

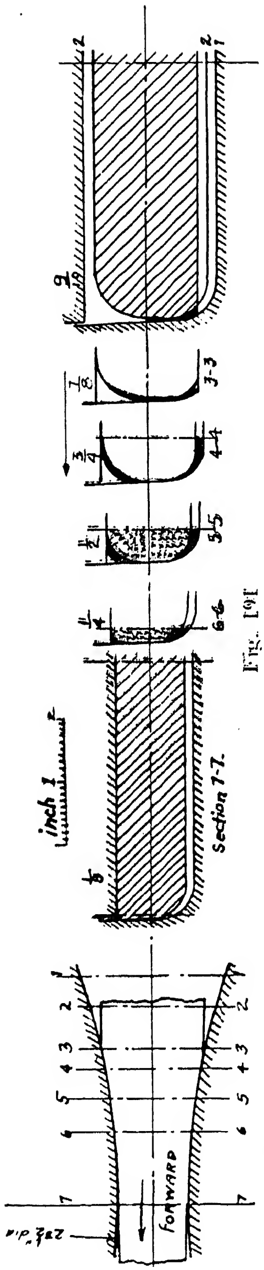


Fig. 191

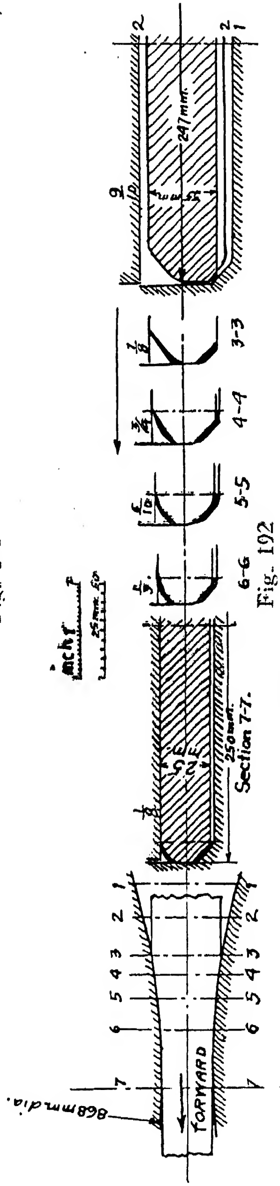


Fig. 192

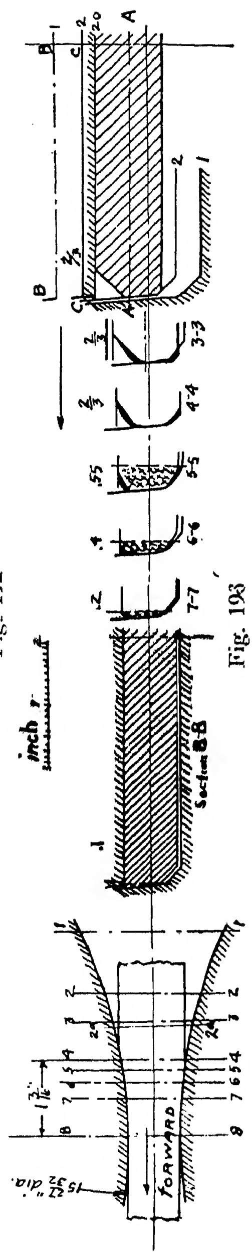


Fig. 193

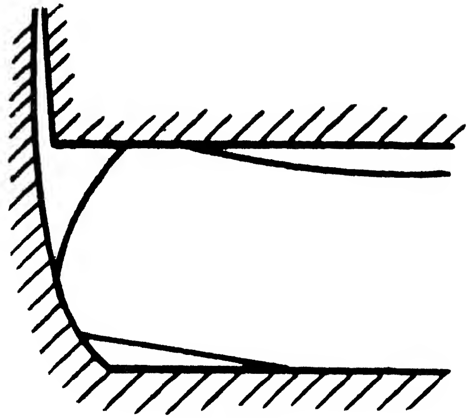


Fig. 194

Inasmuch as the forces to which the bar is subjected act as indicated by the arrows *A*-*A′*, the local deformation about the lower corners of the bar takes place principally in an upward direction. The force *A* which is exerted by the bottom

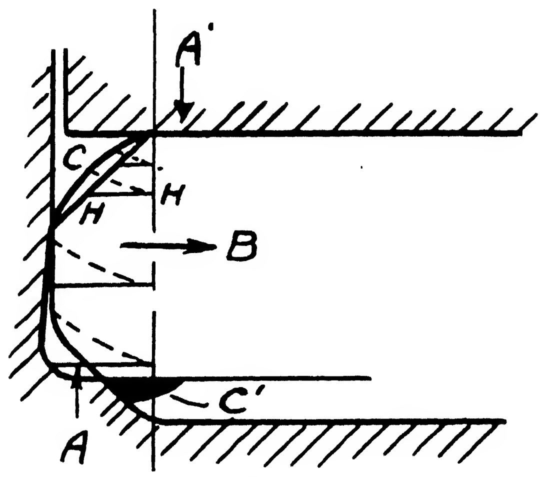


Fig. 195

roll, however, has also a component in the direction of the arrow *B*, which causes a slight lateral compression. It might be suspected that the material displaced by the local de-

formation at the lower corners of the bar would form a wad on the bottom of the bar as shown at C', Fig. 195. A brief study shows that the lower part of the bar is subjected to tension as a result of the forces, and that in consequence the displaced material could not take the form of a wad as shown at C'. Giving due consideration to these various features, it appears probable that about two-thirds of the material displaced at the bottom of the bar between sections 2 and 3 (Fig. 193) will spread upward, the remaining one-third being displaced laterally. An area equal to two-thirds of the displaced area has accordingly been added at the top of section 3-3 in Fig. 193. The above reasoning also applies to the deformation in section 4.

Between sections 4 and 8 of Fig. 193, the entire lower surface of the bar is in contact with the bottom roll, and consequently the entire bar, with the exception of the extreme edges, is subjected to direct compression. In order to determine the factor of upward displacement in the corners, the shape of the projected contact area must be considered. In this case, its length in the direction of rolling is roughly 13/16 inch, whereas its width is approximately 8 inches. It is evident, therefore, that if the spreading of the bar were unrestricted, almost all of the deformation goes into elongation, means that the elongation factor is more than five times the lateral spreading factor. Since the spreading in this case is restricted, almost all of the deformation goes into elongation, and the areas which are not under direct compression (marked by crosses in sections 5 and 6 of Fig. 193) are pulled along by the elongation of the center part of the bar. As the final section 8 of Fig. 193 is approached, the frictional resistance to forward motion becomes less and less.

Both of the above mentioned actions tend to reduce the upward spreading of the material displaced at the lower corners of the bar. By means of careful weighing of the various influences which have been described, the displacement factor for each section was determined. These factors are shown above the successive sections of Fig. 193. It will be observed that the pass is nicely filled, and the natural conclusion is

that either the design of the passes was worked out very carefully, or else the design was the product of long experience.

In Fig. 192, the above process has been used to analyze a pass of a German sheet bar mill. It is unnecessary in this case to make a detailed explanation like the preceding one, but it is desirable to note the features in which this design differs from the preceding one. It will be noted that the pass is about 3 millimeters (⅛-inch) wider than the entering bar. The immediate result is that, in the early sections 2 and 3, the material which is displaced from the corners escapes laterally and causes the bar to touch the sides of the pass even before the direct compression over the entire width of the bar has begun. The final result is that the pass is not as well filled as that of Fig. 193. The passes which follow, however, are designed so that the last pass will be completely filled, and therefore the fact that the pass shown is not completely filled is of no serious consequence. This pass provides only a small amount of sidework to protect the edges of the bar, but it probably produces satisfactory sheet bars, and it certainly is subject to less roll wear—because of the decreased sidework—than the pass shown in Fig. 193.

Fig. 191 shows the analysis of a sheet bar pass of a mill in the central west of the United States. Although the pass allows ⅛-inch lateral spreading, as in the case of Fig. 192, it

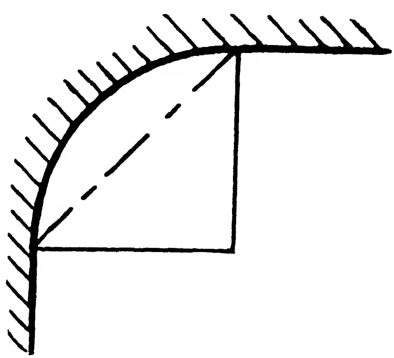


Fig. 196

is filled completely by the final section. This is due not only to the greater thickness of the bar, but primarily to the fact that the corners of the bar are rounded instead of being chamfered like those of Figs. 192 and 193. If the corners had been broken by a straight line between the points of tangency of the fillet, as shown in Fig. 196, the pass would not have been filled. With regard to the amount of sidework and to the roll wear which always accompanies sidework, this pass is similar to the one shown in Fig. 192, the only difference being that in this pass the sidework is more evenly distributed over the whole thickness of the bar. This may be regarded as a well-designed pass.

Sheet bars can also be rolled in two-high reversing mills, but that method is seldom practiced, because it requires turning the bar over between two consecutive passes, for the purpose of avoiding fins. A roll for such a mill, together with the passes, is shown in Fig. 197 (taken from *Blast Furnace and Steel Plant,* April, 1928).

Careful design of sheet bar passes is sometimes considered burdensome. It can indeed be obviated in continuous mills by allowing free lateral spreading and by using vertical edging rolls to provide sidework. The edging rolls, which are usually drag rolls, also serve the purpose of cracking the scale so that it can easily be blown off by a blast of compressed air, water or steam. In noncontinuous mills, vertical drag rolls cannot be used because of complications in the method of driving, but most of the scale can be removed by the use of edging passes. The design of vertical edging passes between horizontal rolls, however, requires some consideration of the thickness of the bar; for the reasons that thin bars cannot be edged without buckling, and that moderately thin bars must be so closely held or guided to prevent buckling that the scale is given no opportunity to drop away.

Tongue and Groove Rolling of Ordinary Flats

The method of rolling ordinary flats in tongue and groove is well illustrated by Fig. 198. Evidently, no edging is done

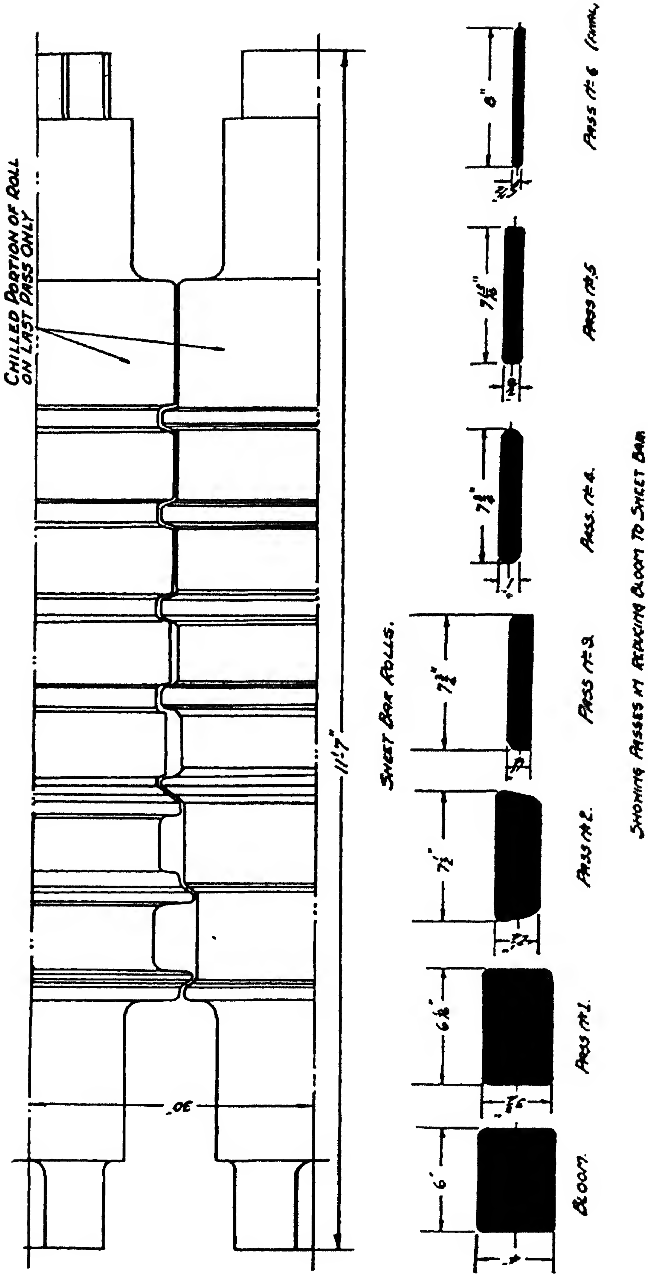

CHILLED PORTION OF ROLL ON LAST PASS ONLY
SHEET BAR ROLLS.
11'-7"
30"
BLOOM.
PASS No 1.
PASS No 2.
PASS No 3
PASS No 4.
PASS No 5
PASS No 6 (FINAL)
SHOWING PASSES IN REDUCING BLOOM TO SHEET BAR

Fig. 197

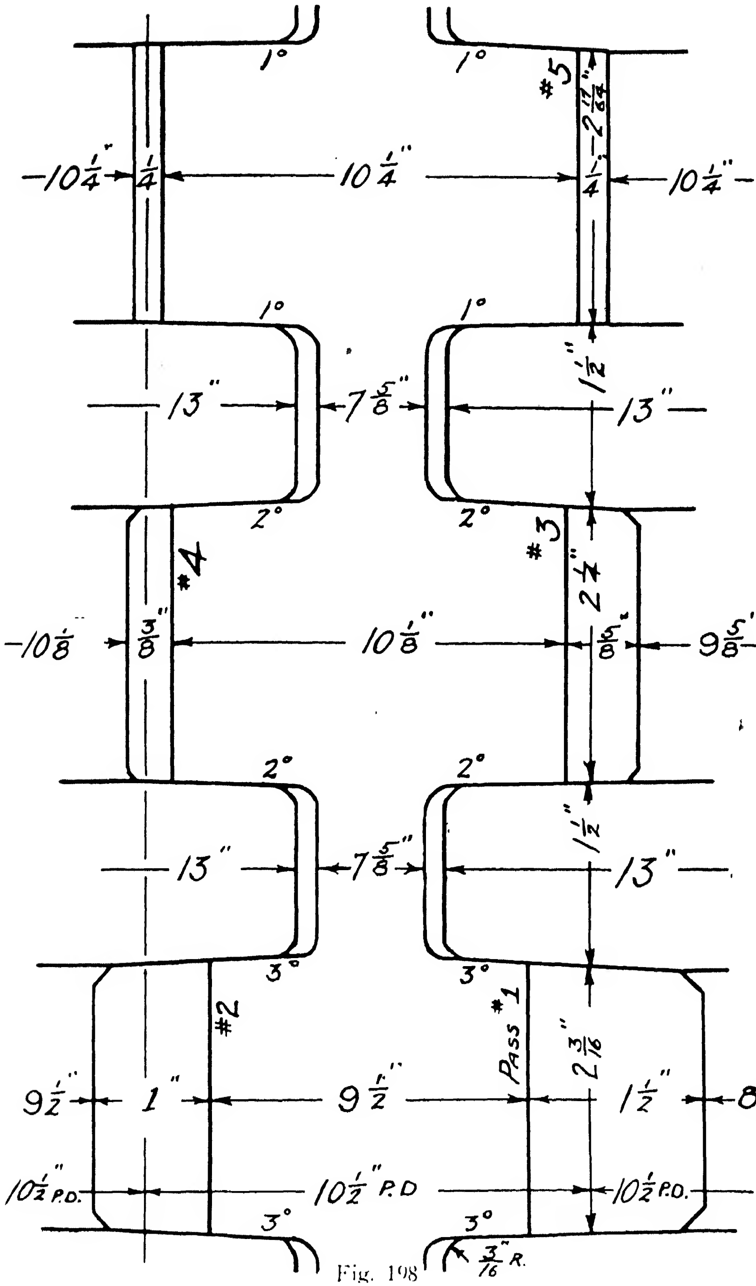

1°
1°
#5
2 17/64"
10 1/4"
1/4
10 1/4"
1/4
10 1/4"
1°
1°
1 1/2"
13"
7 5/8"
13"
2°
2°
#4
#3
2 1/4"
10 1/8"
3/8"
10 1/8"
5/8"
9 5/8"
2°
2°
1 1/2"
13"
7 5/8"
13"
3°
3°
#2
Pass #1
2 3/16"
9 1/2"
1"
9 1/2"
1 1/2"
8 1/2"
10 1/2" P.D.
10 1/2" P.D
10 1/2 P.D.
3°
3°
3/16" R.

Fig. 198

in this set of rolls; in this respect they act the same as most sheet bar passes. The drafts and spreads for a 2¼-inch flat are as follows:

Draft, inch	1/2	3/8	1/4	1/8
Spread, inch	0	1/16	0	1/64
Reduction, per cent.	31.9	37.1	36.7	26.2

It is evident that suppressed spreading takes the place of edging.

In connection with the spreading of the bar in the passes shown in Fig. 198, the fact might be mentioned that in a three-high set of tongue and groove passes, if the bar fills a given pass in the upper row, there can be no spreading in the pass immediately below.

While the roll is shown for a flat of 1/4-inch thickness, it can be used for thicker flats, for instance 5/16-inch or even 3/8-inch, by setting the rolls farther apart. The drafts remain the same, but the reductions (and elongations) become less.

On account of roll wear, it is somewhat difficult to maintain accurate width even in a tongue and groove roll. For that reason, some mills put an edging pass into the roll and go from it into the finishing stand, provided the flat is thick enough to stand a moderate edging pressure without buckling.

Tongue and groove rolling does not get rid of scale on the bar; on the contrary, it rolls the scale tightly into the bar. For that reason, this method is abandoned, wherever possible.

Dimensions of Roll Beyond That Part Shown in Fig. 198

Pass No.	Width, inches	Thickness, inches	Roll Diameter in Inches Top	Middle	Bottom	Sidewall Angle degrees
1a	1-15/16	1⅛	9¾	9¾	9	3
2a	1-15/16	¾	9¾	9¾	9	3
3a	2	½	10⅛	10⅛	9⅞	2
4a	2	⅜	10⅛	10⅛	9⅞	2
5a	2- 1/64	¼	10¼	10¼	10¼	1
1b	1- 3/4	⅞	10	10	9¼	2
2b	1- 3/4	½	10	10	9¼	2
3b	1-49/64	¼	10¼	10¼	10¼	1

CHAPTER III

ROLLS FOR MERCHANT BARS

Hexagons

Hexagonal bars are produced in large quantities for bolts and screws, and occasionally for nuts. They can be so rolled that, in the finishing stand, the clearance between the rolls contains two corners, or else so that two sides of the hexagon span the gap.

The latter method is the more common of the two, because it produces sharp corners without danger of fin formation. The finished hexagon is rolled either from an oval or from an elongated hexagon standing on edge. The former (oval) leader produces very poor hexagons. For that reason, the elongated hexagon has been generally adopted.

Fig. 199 shows the passes of two sizes of hexagonal bars rolled on a 10-inch mill. In each case it takes four passes to convert a square into a hexagon. In this case six passes are shown, but the first two passes are breakdown passes and might as well have been omitted from this study.

The characteristic pass in this series is the leader which is an elongated hexagon with two concave sides. The second pass ahead of the leader is very similar, but it cannot quite completely be squashed down into the right shape. In using these passes, attention must be paid to slight changes in spreading which are caused by material, roll diameter, temperature of bar, and temperature distribution within the bar.

From the explanation given in Vol. I, it follows that the concavity at the top and bottom of the leader must be the greater, the longer the bar has been out of the furnace. In

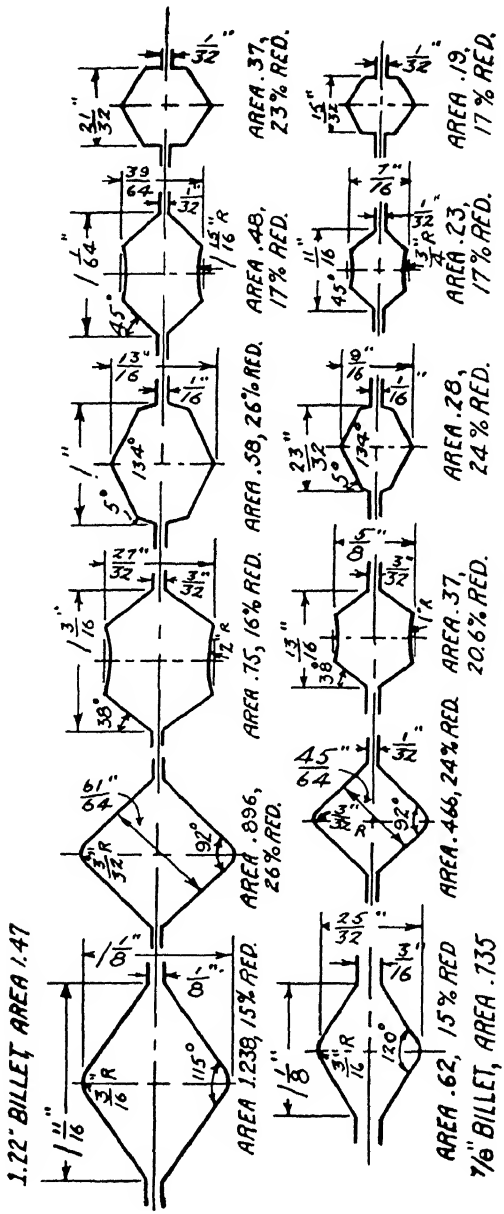

1.22" BILLET, AREA 1.47
AREA 1.238, 15% RED.
AREA .896, 26% RED.
AREA .75, 16% RED.
AREA .58, 26% RED.
AREA .48, 17% RED.
AREA .37, 23% RED.
7/8" BILLET, AREA .735
AREA .62, 15% RED
AREA .466, 24% RED.
AREA .37, 20.6% RED.
AREA .28, 24% RED.
AREA .23, 17% RED.
AREA .19, 17% RED.

Fig. 190

other words: The colder the bar, the smaller the radius, (to prevent overfilling).

Rounds

While a "round" appears to be a difficult section (as far as filling the pass correctly is concerned) it is remarkable how many different shapes of leader passes can be used to produce a practically perfect round.

Up to a short time ago, a broad distinction was made between hand rounds and guide rounds. Large rounds, from 2 inches diameter upwards to about 8 inches diameter were and still are rolled by hand. In this method, a comparatively short leader bar of oval or gothic cross section is guided into and through the finishing pass, while being held in correct position by tongs in the hands of workmen.

In guide rounds (usually less than 2 inches diameter) the billet is reduced to an oval leader which enters the round finishing pass while supported by a guide.

The hand round has the reputation of greater accuracy; the latter is much appreciated for subsequent cold rolling.

Recently, a combination method has been introduced for "forging rounds," which are between 1 inch and 3 inches in diameter.

Hand Rounds

In the rolling of hand rounds, the bloom or billet is usually reduced in gothic passes (see Figs. 166 167, 168) to a square with bellied out sides, see Fig. 165. A comparatively short bar of this section is then finished in the following manner: Workmen hold the bar by tongs with the corners in horizontal and vertical planes and walk towards the mill while holding the bar in this position. The bar is passed through a round leader, the diameter of which is from 3/32-inch to 1/8 inch larger than the finished round, and the corners of which are very amply rounded (see Fig. 200). A mild overfill is formed which becomes somewhat cold and forms a shadow. The bar is then passed through the finishing pass the

first time with the shadow on top, and twice more after turning. The reduction from the gothic leader to the finished round is usually taken as 5 to 6 per cent of the area of the leader. The round passes are tailored with a very large radius, for instance $1/3D$, where D = diameter of round = $2R$, see Fig. 200. As previously mentioned, the part of the bar which lies in the clearance is not reduced and spreads. It is reduced when traveling through the same pass again, after a 90-degree turn.

The smaller the diameter of the round, the shorter the bar must be in hand-rounds, for the following reasons: Roll-

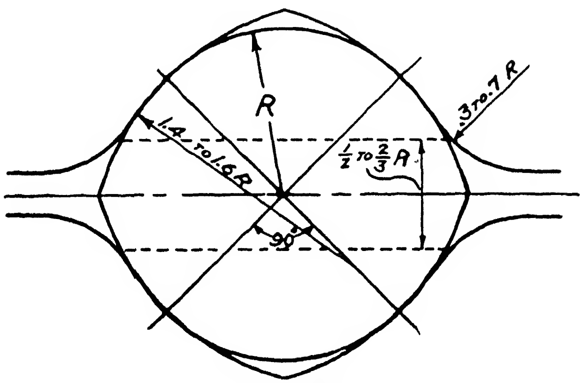


Fig. 200

ing speeds must be low, because the roller has to walk at the speed of the mill while holding the bar. Consequently, a small bar cools too quickly, unless it be short. Furthermore, a small bar has little strength against twisting. Since the angle of twist is roughly proportional to the reciprocal of the fourth power of the diameter, and is directly proportional to the length of the bar, it follows that for a bar half the diameter (of another), the safe length is only 1/16 of the length of the other bar.

These conditions limit the hand round to the values given above.

Fig. 201 shows a section by section analysis of an almost round leader entering a round finishing pass for the first time

through. The leader is 4-3/16 inches in diameter and has a mild overfill on each side. The finishing pass is 4-1/16 inches in diameter and its corners are amply tailored to prevent fin formation. The dimensions refer to the hot bar, the finished diameter of which after cooling would be 4 inches. It will be seen that the bar has a slight overfill, as shown in section *D-D*, after its first passage through the finishing pass. After

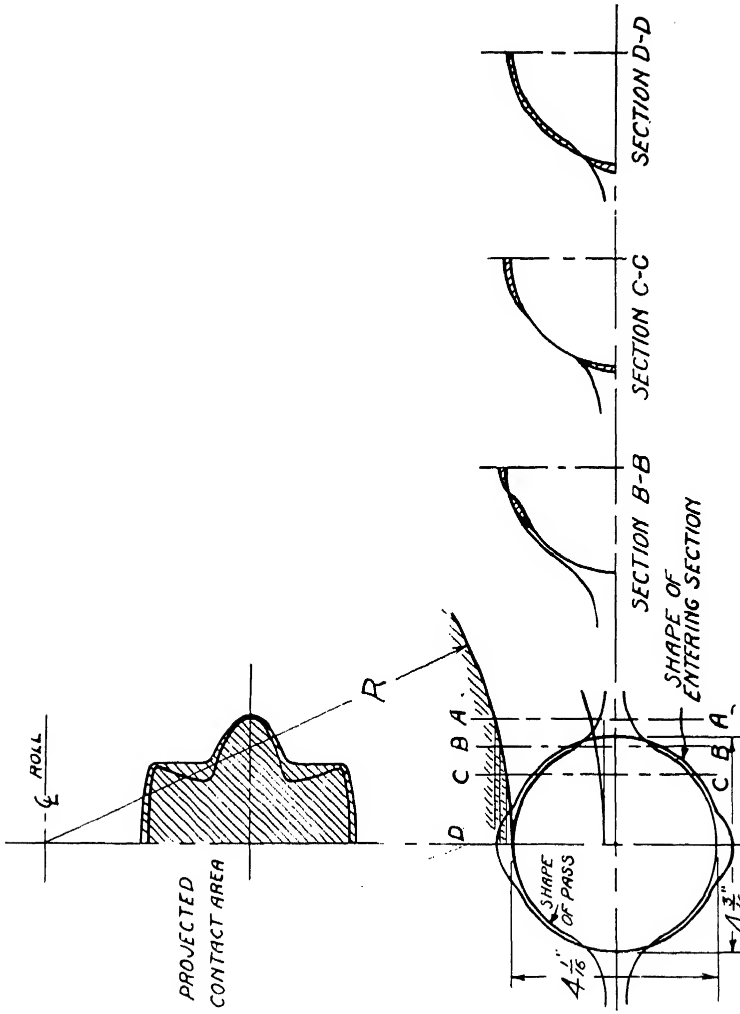


Fig. 201

a 90-degree turn, a second trip through the finishing pass rolls the overfill back into the bar and produces a nearly perfect round. A still smaller overfill may, however, be produced in the second trip through the finishing pass, so that another 90-degree turn and a third trip are required to make a perfect round. In the case of Fig. 201, the reduction in the first pass through the finishing rolls is 5 per cent, while the reduction in the second pass is 1.6 per cent and the reduction in the third pass is even less.

Guide Rounds

Guide rounds are, as a rule, made from ovals, and the latter from squares. Proportions of the oval vary and lie between an "almost circular" oval (1) (2) (4) (6), as shown in Fig. 202, and a very flat or oblong oval (3), (5), (7), (8). The almost circular oval serves for larger rounds (1½ inches to 4 inches) while the very flat oval serves for small rounds (5/16-inch to ⅝-inch). An almost circular oval would be preferable for the small sizes, if it could be used; for the

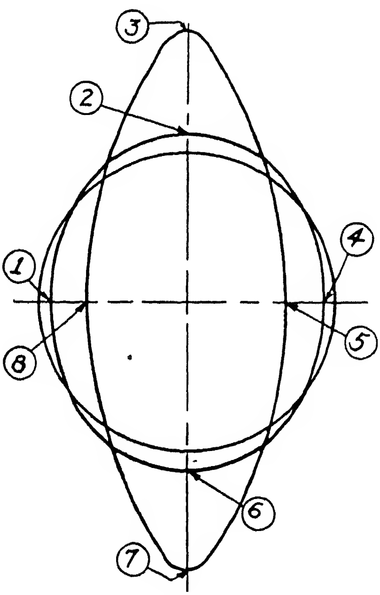


Fig. 202

very oblong oval wears out the finishing pass very soon, which means that it can be used only a short time (the greater the contact length, the greater is the sliding which produces wear). However, the almost round oval cannot be used for small rounds, because the bar would turn over. Guides must have a certain clearance, which becomes a measurable part of the height projecting beyond the circle, if the round is quite small, and if the oval is almost circular. Furthermore the twisting strength of a small section is extremely low which means that the guiding must be even better than it is for a large section.

The width ratio of the leader oval (after edging, ready to enter the round pass) can be expressed by Table XXII, which contains average values gathered from practice.

TABLE XXII

Diameter of Round, inches.	2	1½	1	½	¼
Width of Leader ÷ Diameter of Round	0.87	0.86	0.85	0.80	0.65

The necessary depth of the leader (as it enters the round), or its width, when being rolled is easily computed from two facts.

1. The area of the oval leader is very nearly 2/3 × width × depth.

2. The reduction in the finishing pass lies between the values of 5 per cent and 15 per cent.

Of course, the spreading varies with the reduction, and that is one of the reasons why Table XXII is only an approximation. It is also evident that the reduction must be greater for the ¼-inch round than for the 2-inch round.

The following comment is necessary: In computing the width of the leader pass oval it should be remembered that the oval is seldom filled. Referring to Fig. 203, we note that W_o usually equals 90 per cent of W_p.

An example is offered to clarify this discussion. To determine the dimensions of an oval leader for rolling a 1-inch guide round (neglecting contraction during cooling): The width of the leader is found from Table XXII to be 0.85 inch. Assum-

ing the reduction in the finishing pass to be 8 per cent, the area of the round will be 0.92 $\times$ the area of the leader. The area of a circle is, of course, $\pi/4 \times (\text{diameter})^2$, and the area of an oval or ellipse is $\pi/4 \times$ width $\times$ length. Consequently, the area of the round will be $\pi/4 \times 1^2$, or $\pi/4$ square inches.* The leader

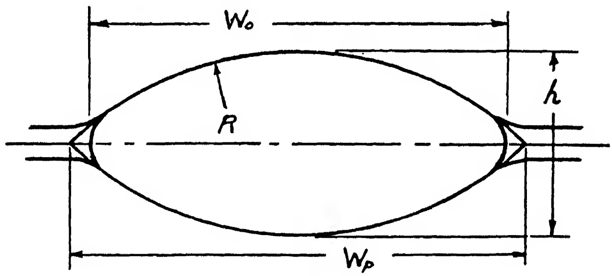


Fig. 203

area will be $0.85 \times h \times \pi/4$, where h is the height of the leader. Therefore,

$$\pi/4 = 0.92 \times 0.85 \times \pi/4 \times h,$$

and $h = 1.275$ inches. Assuming that the leader pass will be filled only to 90 per cent of its width, as shown in Fig. 203, the total width of the leader pass (to the intersection of the sides) will be $1.275 \div 0.9$ or 1.42 inches.

Reductions in the finishing pass can be much greater, (up to 30 per cent) if the finished round may be out of true, and have a rough surface.

A German rule for oval leader is the following (referring to Fig. 203)

$h = 0.99\,d - 1/16$-inch $\qquad W_o = 1.18\,d + 1/64$ inch
$R = 2/3\,d + 1/8$-inch $\qquad W_p = 1.3\,d + 1/64$ inch

where d = diameter of round. American roll designers prefer to make h smaller than the value found from the German rule, see Table XXII.

For rounds of more than 3-inch diameter it pays to depart from the one-radius oval and to substitute a three-radius oval.

*The oval of width W_o being nearly elliptical, the factor $\pi/4$ was used instead of the 2/3 mentioned on the preceding page.

such as shown in Fig. 204. The illustration needs no comment, except that *d* equals the diameter of the round.

The oval leader is usually rolled from a square lying flat. The corners of the square wear grooves in the oval, which fact produces overfilling of the finishing pass. For this reason, two

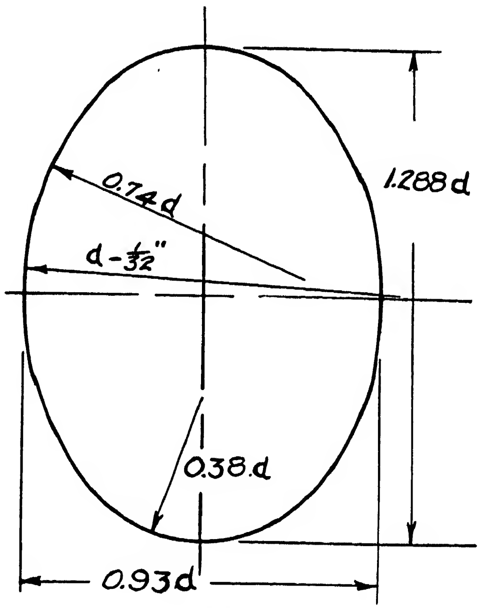


Fig. 204

equal leader passes are provided so that one can be used after the other one has been worn too much. Or else, the preleader square is replaced by other sections.

Fig. 205 shows one method of reducing the wear of the leader pass. For large rounds, the gothic, Fig. 165, is an excellent preleader pass.

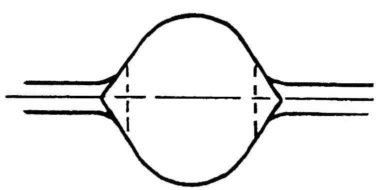


Fig. 205

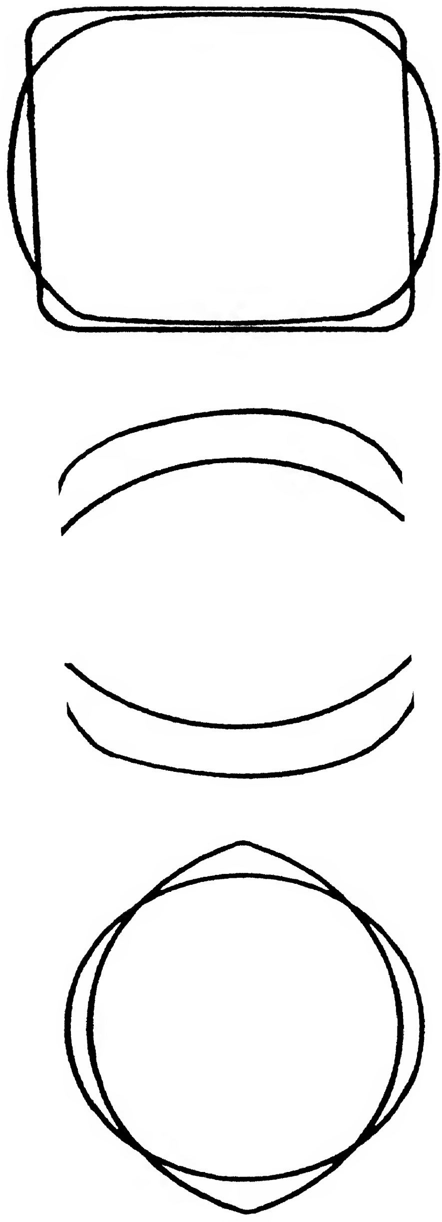


Fig. 206

A good method of changing from the square section to the round section is shown in Fig. 206.

Large rounds, up to 9 inches diameter, are rolled from a ten-cornered leader, as shown in Fig. 207 which shows the leader and the finishing pass for a 6-inch round. This leader was much used for rolling rounds for ammunition shells and is now used for rounds that are to be pierced or are to be sliced and rolled into wheels.

Small and medium-sized rounds are commonly finished on mills the pinion diameter of which equals 6 or 7 times the diameter of the finished round. The larger the round, the less this

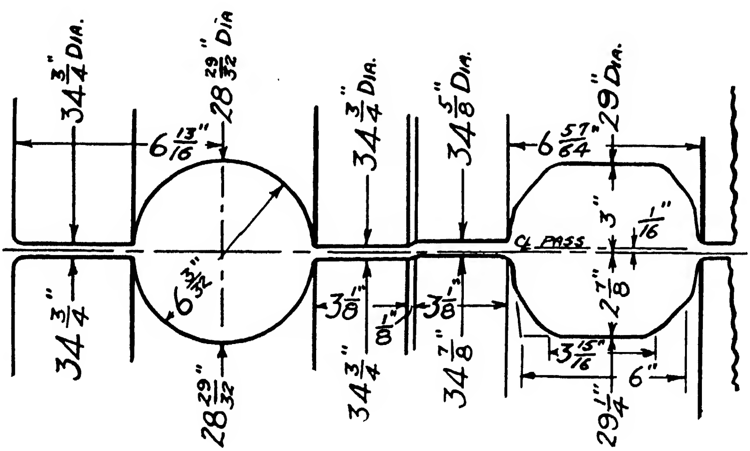


Fig. 207

ratio is maintained. The largest rounds are finished in rolls with a diameter equal to approximately 2¼ times the diameter of the finished round. In the rolling of rounds of 12 inches diameter (for instance), reduction of cross section is secondary to change of shape. The steel is hot. Both circumstances cause the separating force to be small in comparison to the size of the bar.

Another vital difference exists between the finishing of large rounds and of small rounds. For large rounds, the finishing pass can be an exact circle, because there is practically no uncertainty concerning the spreading. (There has been no chance

to develop great temperature differences in the bar.) With medium sized and with small rounds, matters are different. Unevenness in heating or delay in the mill, causes pieces of different temperature (in the same bar, or between bars) to reach the finishing pass. Any bar (or part of a bar) that is somewhat too cold, would certainly produce a heavy fin. The remedy was mentioned in Vol. I on page 142. It is shown in Fig. 200 of the present volume. The relieving at the sides is accomplished by having the roll turner run the next larger plug into the pass to a depth of $r/4$ or even $r/3$. In addition, a generous fillet is provided. The excess spreading cannot produce a fin. Bars which are too hot are slightly flat at the sides. Bars which are too cold are too full, but without a fin.

If very close work is required a sizing mill (with vertical rolls) can be arranged beyond the finished stand. It may be driven by power, but can just as well be built with idler rolls which run on ball bearings. The draft is extremely small (about one per cent of the diameter of the round). A tubular guide is arranged between the finishing stand and the vertical sizing mill. It is important that friction be almost entirely eliminated, to prevent sticking.

Recently it has been suggested to finish a round bar by passing it between two rolls with skew axes. The edges of the disks are concave, with a radius larger than that of the round to be finished. In the direction of the shortest distance between the two axes the distance between the two disks equals the diameter of the round. A certain amount of cross-rolling is obtained, and the bar twirls. The success of the scheme is not yet certain.

Forging Rounds

For the making of automobile crankshafts and of similar articles, a high class round of uniform grain structure and good surface appearance is demanded. It is commonly roughed down in continuous stands, and is finished in a cross country mill.

The general principles are the same as in rolling ordinary rounds, but no twisting of the bar is permitted, except in the

first roughing passes. Some roll designers avoid twisting altogether and alternately use horizontal and vertical passes.

A great advantage of changing from continuous to cross-country rolling appears to lie in the removal of scale. Two separate opinions have been put forth on the reasons for this difference in scaling.

One opinion states that, with passes close together, only a thin layer of scale is added between passes, and is rolled into the bar in the next pass. But if the passes are far apart, the scale becomes thick enough to be cracked off, or to be rubbed off and bumped off on the transfer tables.

The other opinion is based upon the effect of temperature upon scaling. The roughing passes must be made at high temperature, in order to deform the material while it is soft, plastic, ductile. The finishing pass should be made at so low a temperature that very little scaling takes place on the hot bed. In consequence, the roughing passes should be continuous, and should be followed by passes lying far apart with opportunity for cooling between passes. Finally, the scale should be blown off by high pressure water just ahead of the finishing pass.

There is some truth in both opinions.

As stated in Vol. I, approach to a perfectly semicircular finishing pass requires excellently uniform heating, and invariably constant time between discharge from furnace and entrance to finishing stand. This condition is hard enough to fulfill, while the same section is rolled for a long time. It cannot be met, if the section changes, because heating and scaling differ, when material is held in the furnace for an excess time of 40 minutes to one hour, while rolls or guides are being changed.

Quick-Reduction Series

In the rolling of small merchant mill sections, or in the rolling of wire rod, one of the main objects is to reduce from the billet to the final section as rapidly as possible, by which statement is meant that the fewest possible passes are used. In this class of work the arrangement previously described under rolling of squares, in which rolling can be interrupted anywhere and

a square billet is obtained, is of no importance, because we are not interested in intermediate sizes.

In the production of these small sections two problems enter. One of them concerns the shape of the grooves, including maximum possible reductions, while the other one concerns the arrangement of the passes on the rolls.

In addition to the previously mentioned methods of diamond-square-diamond, and flat-and-edging, several other methods or series are in use, namely the all-diamond series, the oval-square-oval series, the oval-diamond-oval series, and the oval-round-oval series. The latter three are in common use for fast reduction particularly in continuous mills. The oval-square-oval series probably originated from the desire to roll by a method which would produce intermediate squares that can be used as starting sections for rounds, hexagons and special shapes. However, each square has only five-eighths to two-thirds the side of the preceding square, which means that the finishing mill must, as a rule, have a great number of passes, if it works in conjunction with this series.

A reducing series must meet the following requirements:

1. Almost all of the deformation must go into elongation, and very little into spreading.

2. On account of the heavy reductions and the accompanying wear, the passes must have such a shape that they can be restored to their correct shape with removal of but a small quantity of material.

The flat-and-edging series (see blooming mill and billet mill passes) meets the first requirement if collars are provided, but it does not meet the second requirement, unless the pass be shaped as shown for instance in Fig. 208. In that case, lateral abrasion is compensated by axial adjustment of the rolls. End thrust is, however, so troublesome that this shape of pass is used rather seldom. Flat-and-edging passes can also be used if the sides of the passes are strongly inclined, as in Fig. 209. If they are used, they are limited to the first few passes immediately after the billet has left the furnace; after the billet has gone through three or four passes, it spreads too much, and the other types of passes are preferable.

The diamond-square-diamond series does not reduce sufficiently fast, for reasons which were previously explained. We then arrive at the oval-square-oval series. It meets both requirements quite well and is extensively used. Fig. 210 illustrates the

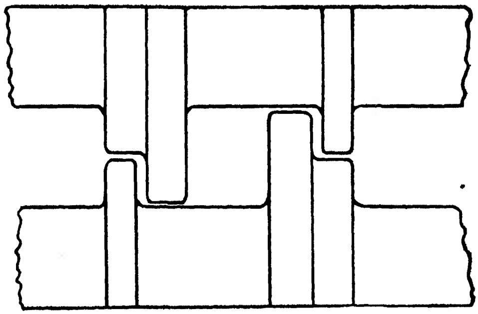


Fig. 208

method of rolling. The ovals are quite frequently replaced by flats with long sloping edges or, in other words, by bastard ovals.

The right hand oval in Fig. 210 is of that type. Still other shapes taking the place of the oval are shown in Fig. 211. The purpose of using these alternate shapes will become clear presently.

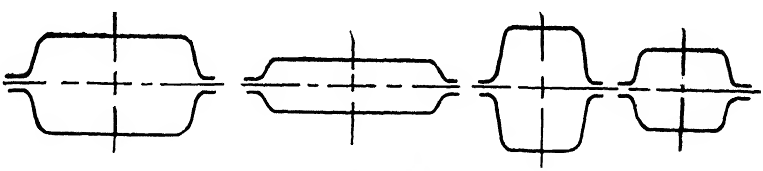


Fig. 209

In Fig. 212, a diagram of ideal elongation is given for an oval entering a square and in Fig. 213 the same diagram is given for a square entering an oval. While spreading modifies the conditions somewhat, the following conclusions are nevertheless true. In Fig. 212, the extreme sides (neglecting spreading) have less elongation than "one." They are stretched, or pulled along by the elongation of the rest of the section. This action, as we know, reduces spreading. The little spreading that actually

occurs does not add much to the area. In consequence, the oval-into-square pass is a good stretching or reduction pass. Fig. 213 shows that the pass "square-into-oval" is somewhat favorable with regard to the prevention of spreading. The sides touch first, and must spread, because the center or main mass of the bar is not yet being compressed. Nevertheless, heavy reduc-

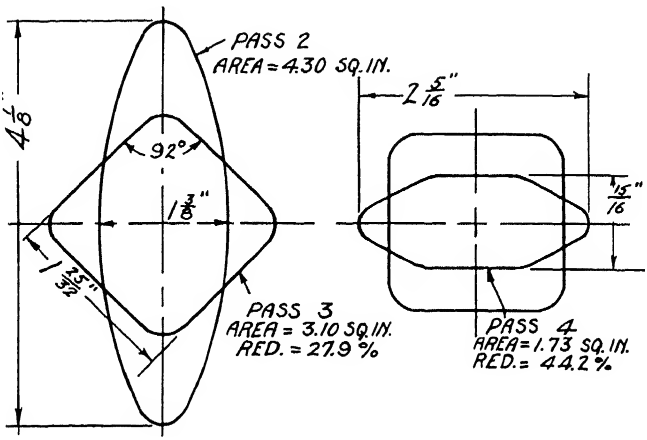


Fig. 210

tions are possible by using heavy drafts and by allowing for the spreading.

This pass (the bastard oval in Fig. 213) wears very rapidly at the points—on the sloping sides—where the bar first touches the rolls. Also, this pass causes the ends of the bar to "fishtail," with the result that the bar becomes difficult to guide. For these

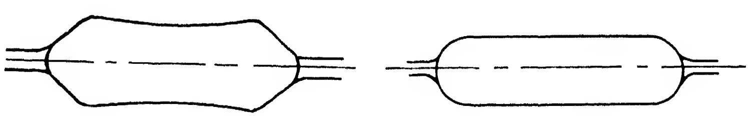


Fig. 211

reasons, and because the rolls become severely firecracked at the points of first contact, the use of this series is avoided by many roll designers.

In both passes (oval-into-square, square-into-oval) reductions up to 50 per cent. or even more, are possible but are sel-

dom practiced, because the rolls wear too fast. The principal advantage of continuous mills or of semicontinuous mills consists in rolling the same section a long time without change. Changing or adjusting rolls is expensive. For that reason, the heavy reductions are now limited to the early passes or middle passes. In them the speed is slow and the material is hot. Both factors reduce wear. In the later passes the speed is high and the material is cold. Both factors increase wear. We therefore encounter reductions between 40 and 50 per cent in the early passes, between 30 and 40 per cent in the middle passes, and between 20 and 30 per cent in the later passes. If the metal-

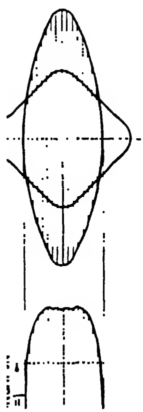


Fig 212

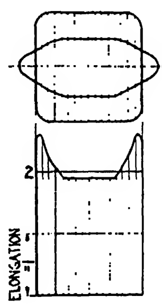


Fig. 213

lurgists learn to give the roller a harder roll that will neither wear nor fire crack, heavy reductions can be used all the way through. As matters are now, the ideal situation would consist in wearing all the passes down to such an extent that they all need dressing at the same time. However, that condition cannot always be attained.

The suggestion might be made here and there that still heavier reductions could probably be obtained more readily and with less wear by the use of larger diameter rolls. The futility of this suggestion becomes clear from the following reasoning: The forward slip, or speed difference between entering and leaving section depends mainly on the per cent reduc-

tion, but it also increases with the size of the roll. The length of the contact arc grows with the diameter of the roll, as seen from Fig. 214, and since wear is proportional to the product of pressure times rubbing distance, it is clear that the wear must be greater on a larger roll. From pages 18 and 86, Vol. I, it will be remembered that the effect is cumulative and that the longer friction path also increases the pressure, which means that the wear is much greater for large rolls. This statement refers to the quantity of metal removed by wear. The larger the roll, the less is the reduction of diameter for a given weight of metal removed by wear. However, the two practically cancel, which means that there is nothing gained by the use of larger

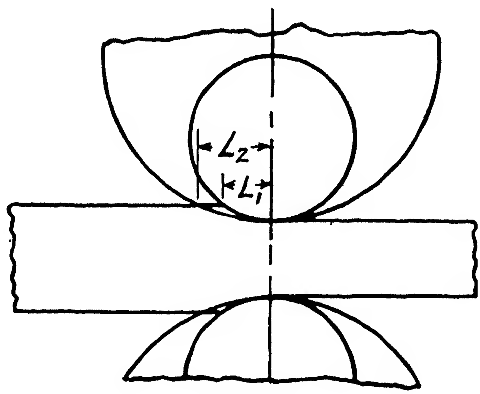


Fig. 214

rolls. In addition, large rolls cause greater spreading, whereas elongation is what we wish to obtain.

To make this matter quite clear, a rather extreme case will be chosen as an example. Fig. 215 shows an analysis of an oval entering a square, ordinary roll diameters being used, while Fig. 216 shows an analysis of the same oval entering the same square, lying in a roll of twice the diameter. Similarly, Fig. 217 is an analysis of a square entering an oval, ordinary roll diameters being used, whereas Fig. 218 is an analysis of the same square entering the same oval lying in a roll of twice the diameter. The greater spreading is immediately evident.

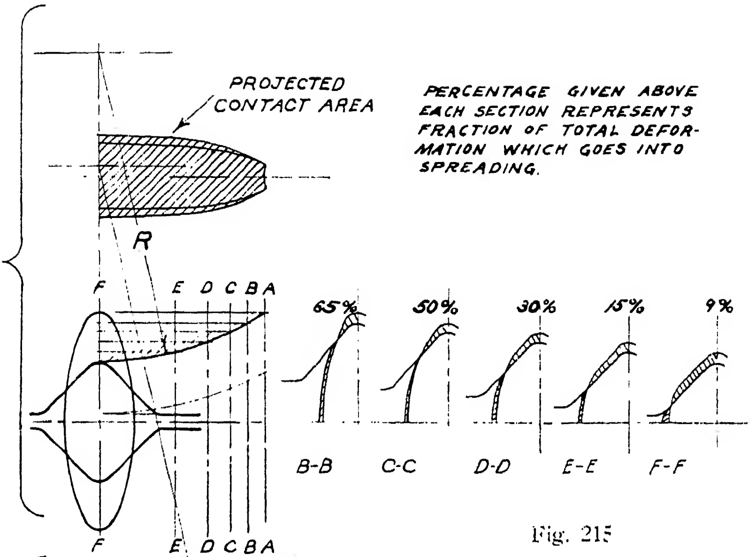


Fig. 215

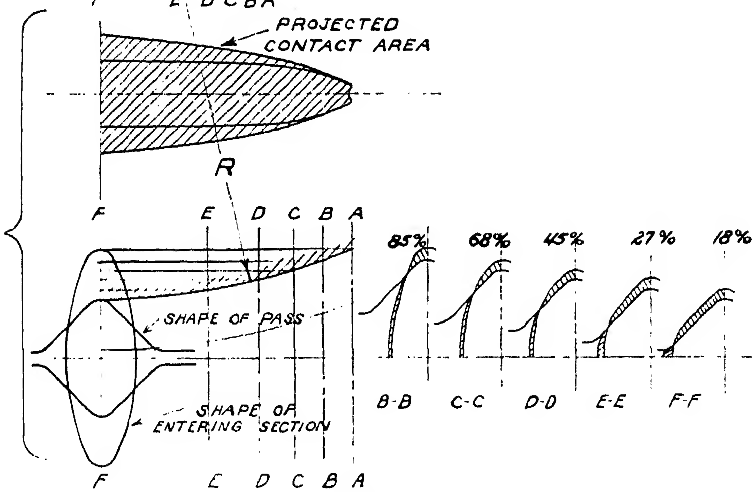


Fig. 216

Of course, the best relation of size of bar and diameter of roll was not found by analysis and calculation, but by costly trial and error.

A relation exists between the flatness or shape of the oval and the reduction. This relation is well illustrated by Fig. 219. To fill the flat oval we must have lots of reduction and lots of

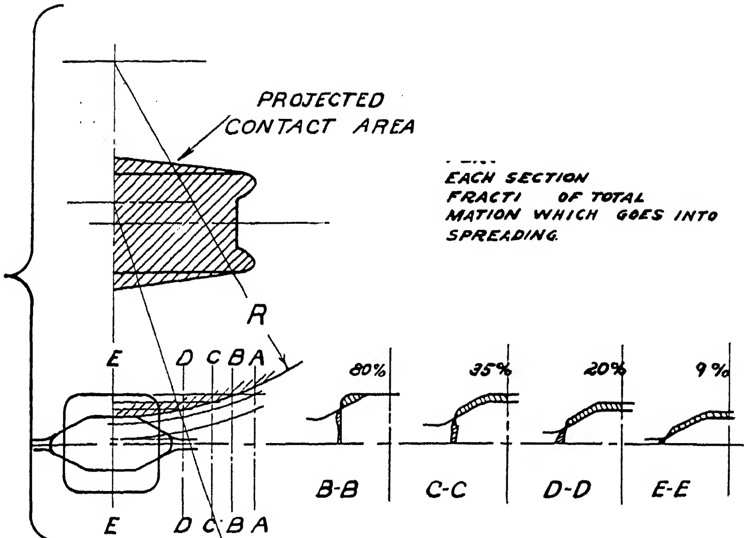


Fig. 217

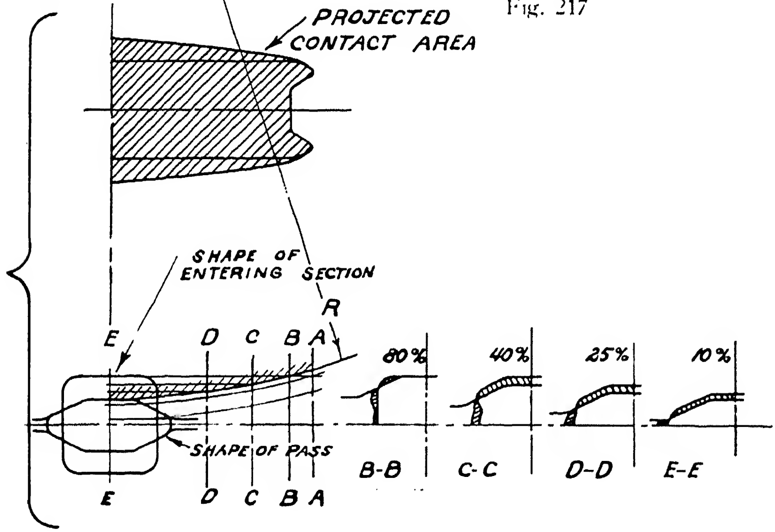


Fig. 218

spreading, whereas filling the less oblong oval calls for less reduction and less spreading.

This reasoning will help to explain the pass-shapes of Fig. 211. The right hand, very flat oval serves for quick reduction,

and the left hand, contracted bastard oval (if it may still be called an oval) is used for extremely quick reductions. When placed on edge, and entering a square on the diagonal, enormous reductions are possible with this contracted shape, without producing a fin. This pass is used whenever it is necessary to get

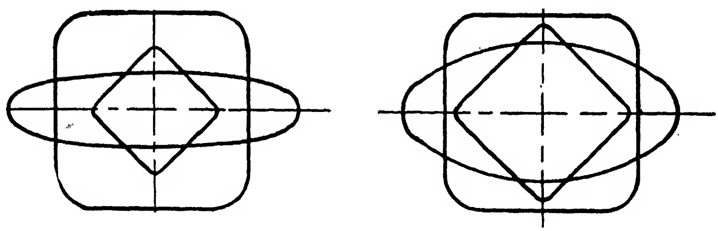


Fig. 219

down in the smallest possible number of passes, without regard to roll wear or quality of material being rolled.

The oval-square-oval series requires that the bar be turned for each pass, 90 degrees from oval to square, and 45 degrees from square to oval. The oval-round-oval series avoids this

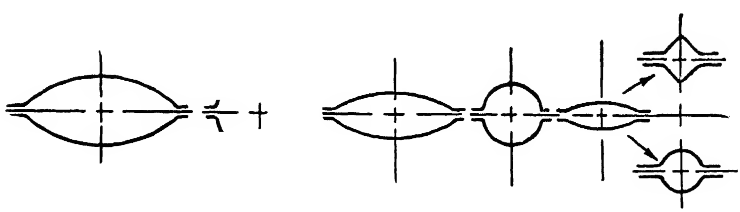


Fig. 220

necessity, as will be seen from a study of Fig. 220. The 90 degree turn from oval to round is still necessary, but the round can enter the succeeding oval without a turn.

While this fact is a help, it is not considered of as great importance as the reduction of roll wear, and the absence of "fishtailing."

If intermediate rounds from the series are to be used, the series of Fig. 220 will not do, because the intermediate rounds

are bastard rounds. The intermediate round passes must not be filled unless temperatures remain absolutely constant, because the slightest change in conditions would produce a fin.

For many years the oval-round-oval series was not applied because it was attempted to fill the intermediate rounds and because many fins were produced. In the series shown in Fig.

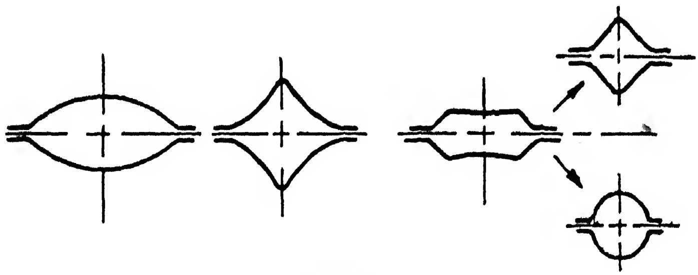


Fig. 221

220, 1¾ squares are rolled to either ⅞-inch squares or 15/16-inch rounds. The reduction is moderate.

A modified oval-square-oval series is illustrated by Fig. 221.

The second problem of any quick-reducing series is the arrangement of the passes in the rolls. In general, this problem concerns the design of rolling mills much more than the design of roll passes. The possible number of variations and combinations is very great, and the study of these arrangements does not belong into a treatise on roll design.

CHAPTER IV

THE ROLLING OF SHAPES

As soon as we leave simple sections such as squares, flats, rounds, and hexagons, we enter the field of what is known as shapes, the commonest of which are the angle, the Z-bar, the "T," the channel, the I-beam, and the rail. Most of these shapes are so commonly used that experience has worked out several excellent methods of producing them between rolls.

While the underlying principles were discussed in detail in Vol. I, the special and separate features which characterize the rolling of each of these shapes will now be discussed.

The Rolling of Angles

The angle forms the transition stage between the simple sections and the irregular shapes, because an angle is nothing but a bent or kinked flat. An angle indeed can be rolled in a manner very similar to that of a sheet bar, the main difference consisting in the necessity of producing a sharp apex, and of finally bending the flat bar into the shape of an angle.

Two methods of rolling angles are in common use, namely the flat-and-edging or butterfly method which is shown in Fig. 222 and the combined reducing and bending method which

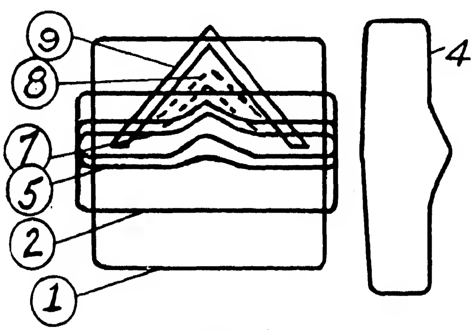


Fig. 222

is shown in Fig. 223. In each case only a few of the principal passes have been shown, so as not to confuse the illustrations. Very small angles are occasionally rolled from a rectangular billet which is entered diagonally as shown in Fig. 224.

It is also possible to keep the angle upright all the time and

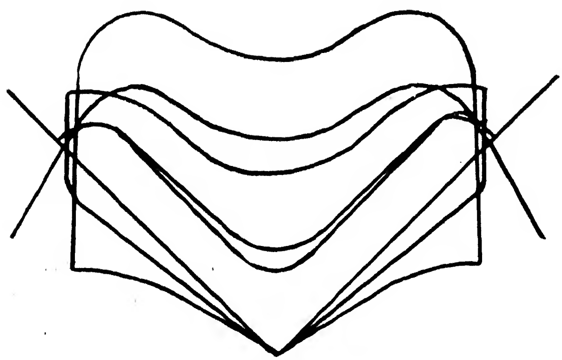


Fig. 223

to roll away one corner, but this method cannot be recommended because it is too hard on the delivery guides.

In the first of these methods the location of the pass with regard to the pitch line is of importance because it is desirable to deliver a straight bar without excessive pressure against the

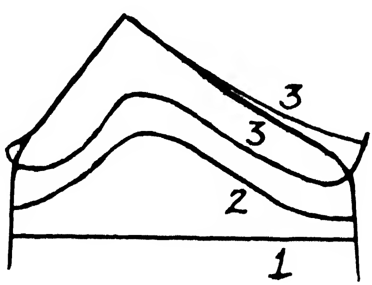


Fig. 224

guides, and because it is desirable to avoid impact of the couplings and spindles.

The combination reducing and bending method has the advantage of taking up less space along the roll body than the

butterfly method, but it results in rather deeply cut rolls. Against this the butterfly method does not require deeply cut rolls, but it allows no edging passes in the later part of the rolling process. Most angles are today rolled by the combined reducing and bending method because the butterfly method takes too much room on the rolls. The butterfly method is used, where no mill large enough for the slab and edging method exists, but where many stands of a small mill are available.

The number of passes which are used to roll an angle from the billet varies with the size of the angle. Small sizes can be rolled in five passes, medium sizes require seven to nine passes, while the largest angles require as many as eleven passes. There are several reasons for this difference. Firstly, small angles are rolled on mills which are quite large in comparison to the size of the angle. In consequence, very big reductions can be taken. Secondly, small angles have thicknesses which are quite considerable compared to the size of the angle. Against this, large angles are rolled on mills which are small compared to the size of the angle, which means that the reductions must be smaller; and finally, large angles have very small thicknesses in comparison with the overall dimensions, so that for this reason also, a greater number of passes must be taken.

Although the butterfly method is not being used as much as it formerly was used, it has two characteristic passes, namely, the edging pass and the bending-up pass. Since they are so characteristic, a section-by-section investigation of these two passes is given here in Fig. 225 and Fig. 226.

Fig. 225 shows what goes on in the edging pass. The analysis follows the method explained on pages 102 to 107 of Vol. I. The sections are numbered from 1 to 6, going from right to left. Between sections 1 and 2, the rolls are just taking hold. At first, contact takes place in a few corners, which means that the pressure is local; it is concentrated on small spots which have to bear a much higher unit stress than the rest of the material. The elastic limit is exceeded in spots but conditions are very favorable to lateral, local spreading so that only about one-third of the deformation will go into elongation.

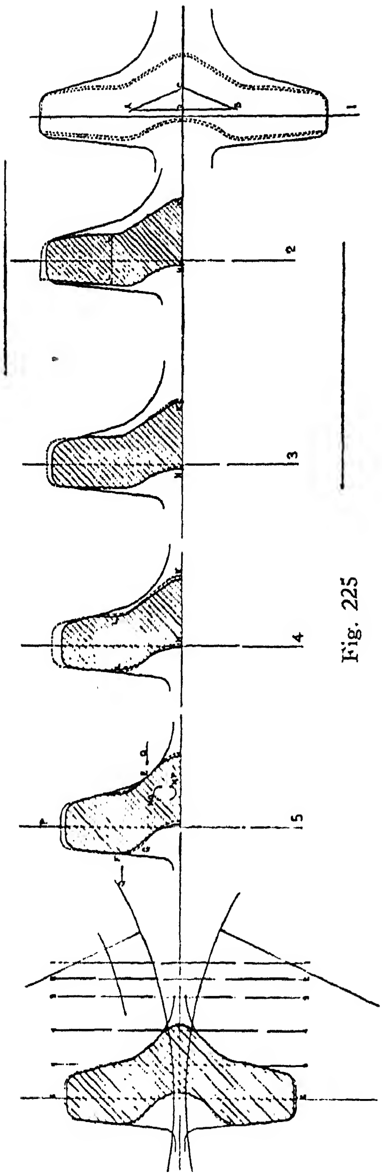


Fig. 225

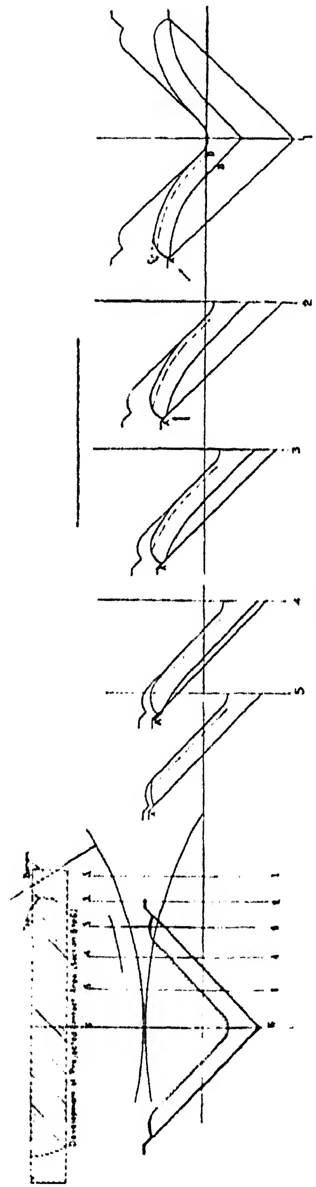


Fig. 226

Between sections 2 and 3, spreading cannot occur as freely as it did between sections 1 and 2, because the steel touches the sides of the groove. This condition would produce considerable elongation, if it were not for the buckling of the section. It is evident that the compressive stress will be quite intense at point *H*, sections 2 and 3, while there may be even slight tension (up and down) at point *K*. If the material were perfectly elastic, the compressive stress at *H* would be almost 2½ times as great as it is in *LL*. Forward motion is still difficult. It is, therefore, probable that only 1/3 of the displaced area goes into spreading, as indicated, while the other half of the remaining compression height decreases distance *AB*, increasing distance *CD* by a corresponding amount.

The same relations exist more or less between sections 3 and 4. The wedge-shaped grip of the rolls extends so far down, and the collapsing action is so great, that only a small fraction of the total deformation can go into elongation, while its greatest part consists in collapsing. Between sections 3 and 4, the compressive stress at *H* is approximately four times as great as the compressive stress in the section *LL*. Consequently, the probable shape of the stock in section 4 was sketched on the basis of 25 per cent of the displaced area going into elongation, 25 per cent going into lateral spreading, and 50 per cent being accounted for by collapsing or buckling. In section 4, this latter action has almost reached its greatest intensity.

Further intensification of this action is checked by the steel's coming in contact with the rolls at point *E* (section 5). This contact occurs somewhere between sections 4 and 5. The immediate effect of this contact is the setting up of a couple counteracting the bending caused by the bending force *P*. Study of the upper half of section 5, shows that the moment *MP* caused by *P* turns counter-clockwise. The result is that the bending or the buckling effect is greatly diminished. Allowing for the circumstances that, in section 4, the steel has not yet touched the rolls at *E*, and in consideration of the fact that the shape in section 5 must be the result of all forces acting between 4 and 5, one-third of the displaced area was assumed to go into elongation, one-quarter is accounted for by bending,

while the rest goes into spreading, which, of course, means growth of cross section counteracting the reduction of area which is caused by the approach of the roll surfaces. Spreading occurs to the greatest extent where the forces favoring it find least resistance. In the section under discussion that place is *G*.

Very much the same reasoning applies between 5 and the final section 6, except that the total friction resisting forward motion is now very small. But the resistance to spreading at *G* is likewise very small, while further collapsing is almost impossible. In consequence, section 6 was laid out on the basis of one-half of the deformation going into length, and the other half going into spreading, mostly at *G*. The edging pass cracks the scale and drops it.

Fig. 226 shows how the "butterfly" is bent into an angle with straight sides. As before, the bar moves from right to left. Sections were again made through the roll and through the angle to investigate the gradual process of deformation. Section 1 shows the angle as it comes from the preceding pass. It is shown as touching both the top and bottom rolls. This need not necessarily occur, because the guide may, and probably will, enter the angle so that the latter touches one of the rolls ahead of the other. However, that makes little difference, because the roll which comes in contact first will soon deflect the whole bar so that it also touches the other roll. From sections 1 to 5, there is practically no compression. All deformation is caused by bending within that range.

Point *A* in sections 1 to 4 denotes the point where the entering section first touches. Form a study of the drawing, it is evident that a sliding action takes place between the angles and the rolls. This sliding has several effects. First, it wears one of the rolls over the range marked *C-A* in section 1; second, it sharpens the corner at the tip of the angle; third, it increases the tension which is produced by bending up of the angle. If the bending force were applied in the direction of the arrow at A, section 1, then the neutral axis would lie in the center of the width of the angle. But since the force is applied as indicated by the arrow at *A*, section 2, the neutral axis is shifted to about one-quarter of the thickness from the inner edge. The amount

of elongation which results from bending up can, therefore, be quickly ascertained by measuring the distances *AB* and *CD*, section 1. Then $(CD - AB) \div AB$ is the unit for specific elongation which results from the bending up. A perfectly plastic material will stand a single (not repeated) elongation of 100 per cent if lateral contraction is prevented, and will stand much greater elongation if lateral contraction is permitted. In the present case the unit elongation is about 10 per cent, with lateral contraction prevented. Consequently, no cracks need be feared, either with steel or wrought iron. If the unit elongation by direct tension across the slag grain in wrought iron exceeds 15 per cent, cracks are likely to appear. There is nothing particularly definite about the value 15 per cent, because the nature and extent of the slag enclosure modify the limiting elongation. With steel, a greater amount of bending up than here shown is permissible; the limit is set by other reasons, particularly by wear of the rolls.

A different action begins just as soon as the angle touches both rolls over its whole length. The regular compression and elongation which forms the object of all rolling processes, takes place between sections 5 and 6. The amount of compression in the finishing pass is usually very small, so as not to destroy the accuracy of the final pass. A slight compression is desirable, because it counteracts, to a certain extent, the loosening influence of the tension caused by the bending up process. The amount of lateral spreading which occurs in this pass is of interest. Above section 6 a development of the projected contact area has been shown. It is somewhat different for the top and bottom rolls. The contact area is then a rectangle of ratio of sides of about eight to one, which means that less than one-tenth of the displaced area will go into spreading. The pass, therefore, barely fills. No fin will be produced.

Since the combined reducing and bending method of rolling angles is today the standard method, several examples of the passes are given in Figs. 227, 228 (Plate I) and 229.

In Fig. 227, as in many of the later illustrations, the tail marks at the sides of the pass indicate the split of the rolls.

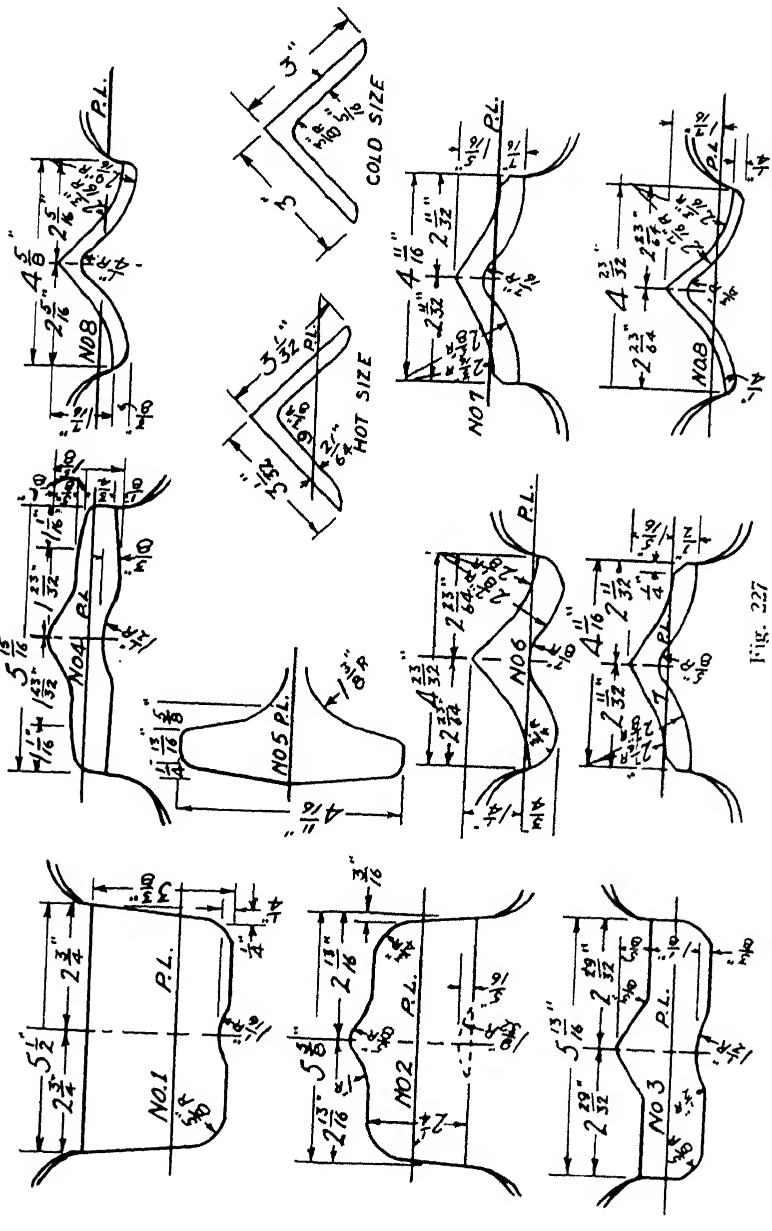


Fig. 227

PL = pitch line. Pass No. 5 is practically identical with the pass analyzed in Fig. 225.

In Fig. 228 (Plate I) the arrangement of passes and collars is interesting. Evidently the roll designer used judgment. The collars may be made slightly narrower, but not much.

Since the angle is unsymmetrical top and bottom, it may be expected that the shape of the projected contact area must be different top and bottom. The expectation is borne out by Fig. 230, which shows the billet from pass 2 of Fig. 228 entering pass 3. The construction lines are shown, and little com-

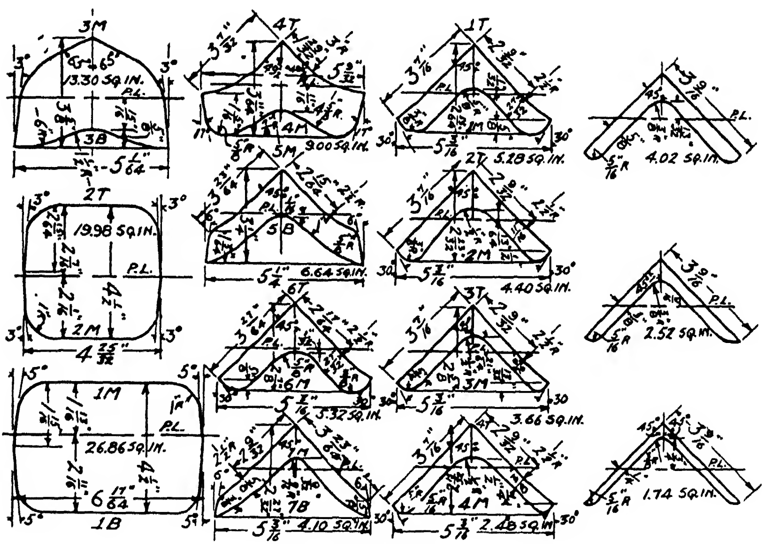


Fig. 229

ment is needed. The solid lines show the projected contact area as found by construction. The dotted lines show the probable shape which establishes itself due to the yielding of the bar.

The passes of Fig. 228 lie halfway between the butterfly method and the standard method. In a study of the templets of Figs. 227, 228 and 229, or of similar passes, the location of the parting of the rolls can readily be located not only by the above mentioned tail marks, but also by the sharp corner. It will

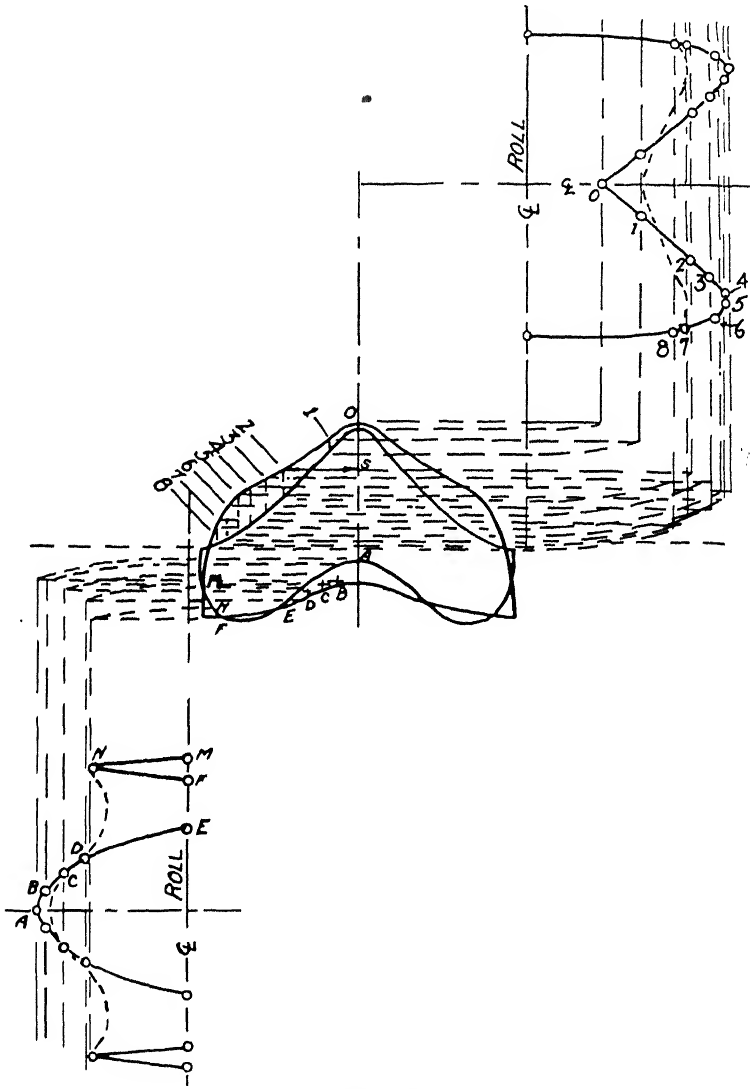


Fig. 230

be noticed that the tips of the legs of the angles are in some cases sharp, and rounded in other cases. The sharp point indicates the parting or clearance between the rolls. The metal does not fill the point, because the radius in the preceding pass was

made large enough for that purpose. (See Vol. I, pages 140, 141.)

In most of the passes, spreading is almost entirely prevented, for the purpose of protecting the edges. The total width of the finished angle is but little greater than that of the billet.

In all structural shapes, the trade demands several thicknesses of a given size of section. Angles are made in a number of these thicknesses, which vary from 2 (for small angles) to 6 (for large angles). The problem is to obtain these thickness variations with the smallest number of rolls or roll changes.

A very simple but crude method consists in setting the rolls farther apart. If the metal fills the finishing pass, the method is crude because the length of the legs of the angle is changed

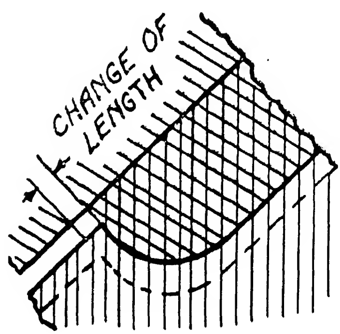


Fig. 231

thereby to a slight extent, as shown in Fig. 231. Correct length for all thicknesses is obtained by separate finishing passes and separate leaders for the various weights of angles.

It is, however, possible and rather common practice to produce angles of the same nominal size, but of three different weights, in the same finishing pass. This is done by designing the passes for the intermediate weight of the three weights desired, and by varying the roll adjustment in the finishing pass to produce the heavier and lighter weights. In order to keep the

dimensions of the finished product within the usual tolerances, it is necessary to vary the draft in the leader as well as in the finishing pass when changing from one weight of angle to another. No stops are then used in the finishing pass; consequently the size of the leader must be so adjusted that the spreading in the finishing pass will produce accurately the required dimensions of the finished angle.

Angles with Unequal Legs

These angles are rolled by the same methods as those used in the rolling of angles with equal legs. The following facts should, however, be mentioned:

If an angle with unequal legs is placed at an angle of 45 degrees to the roll axis, a side thrust is produced, and the rolls are cut rather deeply. The end thrust very easily results in unequal thickness of the two legs, and produces twisted (corkscrew) angles, in spite of well set delivery guides.

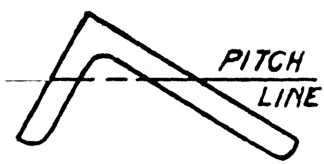


Fig. 232

To overcome end thrust the angle can be placed so that the clearance (split) between the rolls is at the same distance from the roll axis, see Fig. 232. While this arrangement practically eliminates end thrust, it does not eliminate roll spring. Assuming equal draft to be taken on the two legs, the force between the long leg and the rolls would be greater than that between the short leg and rolls. Greater roll spring would therefore occur over the long leg than over the short leg, with the result that the long leg would be reduced slightly less than the short leg. This condition is objectionable only in the later and colder passes. For that reason the draft is made smaller for the long leg than for the short leg in the last passes, which means that it

must be made greater in the first passes. This distribution of draft is shown in Fig. 233, Plate II.

In rolling angles with unequal legs, it is possible to reduce the number of finishing passes required, by rolling angles of the same thickness, but of different lengths of legs (for instance 3 inches × 2½ inches and 3 inches × 2 inches) in the same finishing pass.

Square root angles are rolled in the same manner, but the radius at the root is made smaller, until a sharp corner is obtained in the finishing pass. Square root angles cannot be rolled by a semi-butterfly method.

Z-Bars

A section which, in former years, was very popular, but which is rolled rather seldom at the present time is the Z-bar.

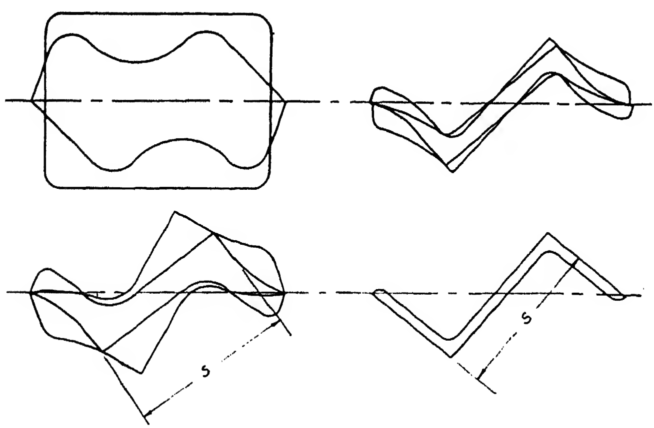


Fig. 234

It consists of two angles joined together, with the outer flanges pointing in opposite directions. The method of rolling is very similar to the combined reducing and bending method for rolling angles, as illustrated by Fig. 223. A set of passes for a Z-bar is shown in Fig. 234. It will be noted that the final depth *s* of the Z-bar appears early in the formation of the bar and that the dimension in question changes but little.

Channels

Like a Z-bar, a channel also consists of two angles fastened together at their tips, but both outer branches point in the same direction. The rolling of channels might, for that reason, be expected to have features similar to those of rolling angles. A channel can indeed be rolled like two angles side by side (see Fig. 235), but this method is seldom used, because it takes up altogether too much space along the rolls.

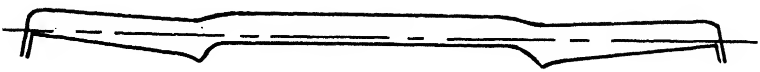


Fig. 235

As a rule, channels are rolled from square or rectangular billets or blooms. In the rolling of large channels, part of the work of shaping is done in the blooming mill, which rolls "beam blanks" in that case.

In the process of transforming a rectangular shape into a channel shape, several ways are open, each of which has its advantages and disadvantages. In other words, it is possible to change from a rectangle to a channel by passing success-

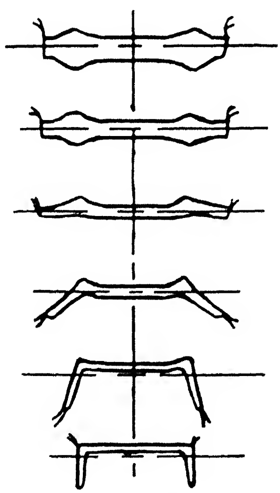


Fig. 236

ively through various intermediate shapes, the later being very dissimilar in the different methods. Figs. 236, 237 and 238 show three different methods. In each case, only a few of the passes are shown for the sake of simplicity, others having been omitted.

The method illustrated by Fig. 236 is called the butterfly

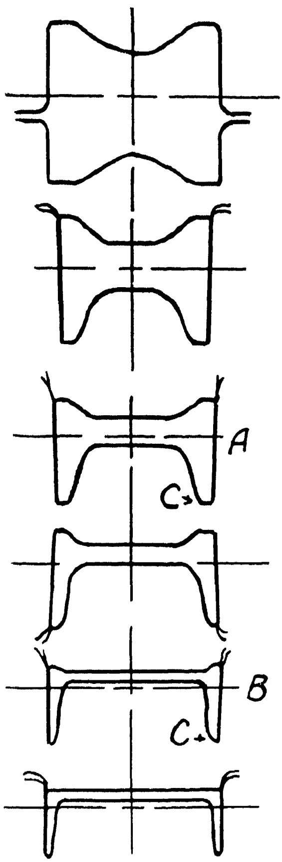


Fig. 237

or bending-up method. It corresponds to the butterfly method of rolling angles. Rolling by this method involves very little grinding action (due to speed differences between the two rolls), because all of the heavy reduction work is done by slabbing

before the bending begins. On the other hand, the channels, while still in the shape of flats, take up a lot of space in the direction of the roll axis. The lumps in the intermediate passes serve two purposes: first, they are needed to furnish the material for the outer corner in the bending process. But they are made much larger than is necessary for that purpose. The excess serves the purpose of protecting the flanges from tearing. From Vol. I, pages 88 to 90, it is known that wide sheet bars, skelp and plate, do not spread on account of the ribbonlike shape of the projected contact area. In order to insure easy entering of the bar straight through, it is desirable to have each following pass a

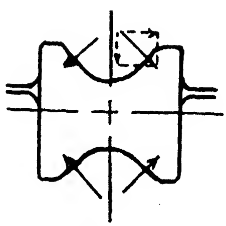


Fig. 238

little wider than the preceding one. And to insure, not only filling under these conditions, but also some side pressure, it is necessary to compress more heavily near the edges than directly in the center. And that condition is attained by the bumps or lumps, as shown.

The method illustrated by Fig. 237 is called the beam roughing, or temporary flange method. The beam blank is started just like the blank for an I-beam, but the temporary flange on one side is removed step by step. This method requires less length of roll per pass, but it produces more grinding action between the rolls and the bar than the method of Fig. 236. The great inclination of the interior faces in the early passes has a very good effect. The pressure of the rolls being inclined, as indicated by the arrows, Fig. 238, causes the material in the web-to-be to not all go into length, but to flow voluntarily into the side parts which are to form the flanges. Consequently, there exists no tearing action on the flanges in these

early passes. In the later passes, the tearing action is avoided by pressing the temporary flange into the permanent flange. If too much of the temporary flange is removed in one pass, a fin is produced. It is, therefore, evident that, by careful design and adjustment of rolls, the flange can be protected, and that work can be done upon it. This is particularly noticeable from the study of passes *A* and *B* in Fig. 237. In both passes the flange is pushed down into the dead hole, so that its edges, *C*, can be subjected to strong pressure.

The method illustrated in Fig. 239 is similar to the one in Fig. 236, except that the bending-up begins sooner. It requires

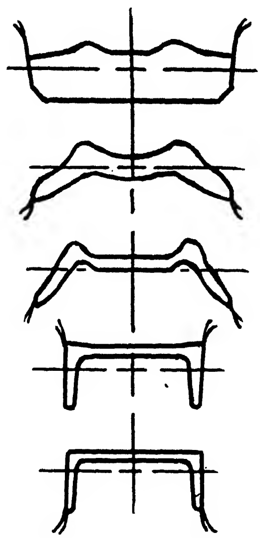


Fig. 239

less roll length, but the grinding effect due to difference of roll velocities is greater. The passes shown reveal the bumps which are necessary for the protection of the edges. The method shown in Fig. 239 is used for channels with deep flanges (ship channels), which would cut the rolls too deeply, if rolled by the beam roughing method of Fig. 237.

One pass from each of the three processes will now be analyzed, by means of the method of making sections through rolls and bar, at right angles to the latter, ahead of the center

of the roll. From each process of rolling, that pass was selected which most clearly shows the peculiarities of each of the three processes. Fig. 240 illustrates that pass of the bending-up method in which the greatest bending occurs. When entering the pass, the bar touches the rolls as indicated in section I. It will be shown later on, that the bar is in contact with the rolls at section I at entrance only, and that no contact takes place in that section for the rest of the bar. The corner, *C*, of the upper roll gradually and steadily bends the flange around the rounded projection, *AB*, of the lower roll. The amount of bending is so great in the short distance I-III, that the bent flange at section III reacts and bends the flange in sections I and II more than the position of the upper roll would indicate. This backwardly

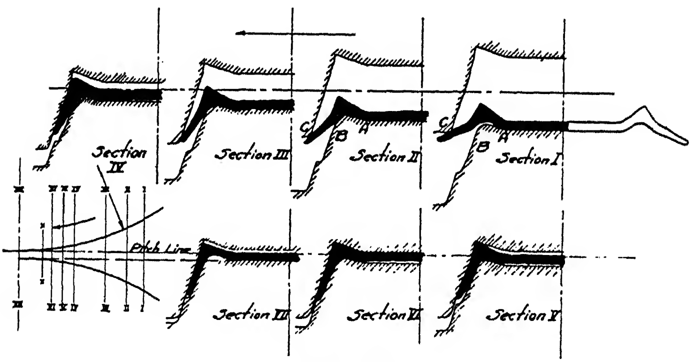


Fig. 240

extending influence of the quick bend stops contact of the bar and roll at point *C* in these two sections. Likewise, the bar has been raised by the bottom roll in section III, so that it is lifted away from the lower roll in sections I and II. It is quite evident that there is no contact between bar and roll in these sections, as above indicated.

The amount of bending in this one pass is very great, so great that cracking of the steel would occur if all, or almost all, of the bending deformation were concentrated at one spot. The latter possibility is prevented by the gentle curve of the corner, *AB*, of the bottom roll. If deformation were to be concentrated in one spot, the bar would make contact with the bottom roll.

and would be bent as indicated in sections I and II; that is to say, with the point of greatest bending gradually progressing from the root of the flange towards its top. Up to and including section V, bending of the flanges and a slight bending of the web (caused by transmission of the bending moment) are the only deformations taking place in the bar. At section VI, compression begins at the corner. At the section marked *X-X*, compression of the web begins. It ends, of course, at section VII. Compression of the flange begins slightly ahead of section VI. On account of the inclination of the flange, compression of the latter must begin ahead of that of the web, if the same draft is to be obtained in both members.

The reduction in the web is about 15 per cent, while that of the flange is about 11 per cent. The flange would therefore be shortened, and would not fill, if it were not for the excess

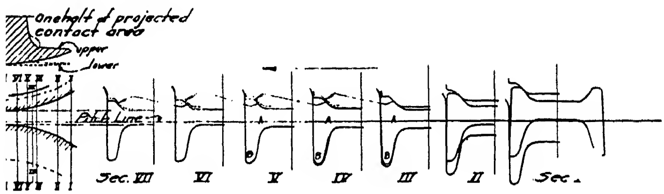


Fig. 241

material in the corner between the flange and web, which excess material is shoved down into the flange, so that the latter just fills.

No work is put on the edge of the flange in this pass. The necessary side work was obtained in the passes ahead of the one just analyzed.

Fig. 241 is a graphical analysis of a pass from the beam roughing method of rolling channels. The temporary flange lies alternately in the live part and in the dead part of the pass, if the channel is rolled in a three-high mill. In order to free themselves from the rolls, the flanges must be inclined, which means that they must be bent "in and out" alternately. This fact shows up very well in sections I and II of Fig. 241, where

the main flange strikes at the bottom outer edge. The action in these sections is that of bending the flanges, and of allowing the main flange to slide into place. From section III, Fig. 241 on, the flanges are compressed all the way over to section VII, while compression of the web takes place only between the limits of sections V to VII. This difference in duration of compression introduces a peculiar movement of the material. From sections III to V, the flange only is compressed. The compression cannot altogether go into elongation, because any elongation of the flanges has to take the web along. Hence there must be some spreading. Material at the point marked *A*, can escape into the web and assist in its elongation. Material at point *B* cannot migrate into the web, so that space for its spreading must be provided. Note that the pass into which the flange enters is slightly wider at the bottom, allowing room for the spreading. This condition holds to section V only. From there on, the reduction (in per cent of initial section at V) is much greater in the web than it is in the flanges. The web tends to elongate more than the flanges and pulls the latter along. The material at *A*, which first migrated from the flange into the web, now returns to the flange. (See also Vol. I, Fig. 111.) The reversed direction of flow mentioned here is the cause of the severe pitting which commonly occurs at the corners of rolls around which such flow takes place.

A rough calculation of the probable spreading between sections V and VII may be of interest. The elongation of the web alone (with spreading prevented) would be 32 per cent, while the elongation of the flange alone would be 8 per cent. But the ratio of the area of the web to that of the flanges is $4\frac{1}{2}$ to 7. Hence, the resulting elongation is $(0.32 \times 4.5 + .08 \times 7)/11.5 = 17.4$ per cent, unless the shape of the projected contact area gives one of the two factors an undue preponderance. But if 17.4/32 of the ideal elongation of the web goes into real elongation, the other 14.6/32 must go into feeding the flanges. The displaced area of the web is two square inches, so that an area of $(14.6 \times 1 \times 2)/(32 \times 2)$ or 0.455 square inch goes into each flange to make up the deficiency. This calls for a spreading of about 0.33 inch into each flange. The shape of the projected contact area of the web ($5\frac{1}{2} \times 2\frac{1}{4}$) is that of a

rectangle of ratio of sides of 2:4. According to the reasoning given in Vol. I, approximately two-thirds of the displaced area would go into elongation, and one-third of that area would go into spreading, if there were no lateral restraint. Hence, ½ × 1/3 × 2 = 0.33 square inch would naturally go into each flange. The difference between 0.45 square inch and 0.3 square inch is not sufficiently great to cause any pulling-down of the flanges, but they do not quite fill in section VII.

Considerations of the same character do not enter into Fig. 242, which is an analysis of a pass from the combination or halfway method. Like the pass of Fig. 241, that of Fig. 242 is

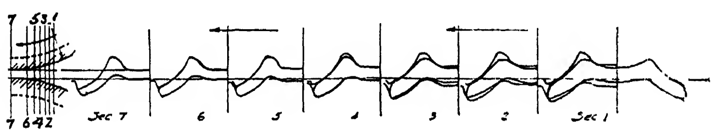


Fig 242

far enough away from the finishing pass to make side work on the edges desirable.

Between sections I and II, there occurs only bending of the section coupled with local deformation at the tip of the flange; that latter is very similar to that discussed in connection with the rolling of sheet bars. The same is more or less true between sections II and III; that is to say, no elongation of any account occurs. From section IV on, compression and elongation begin. However, there is no compression in the corner between flange and web until somewhere between sections V and VI. Just why the designer of the series of passes from which this example is taken provided less compression in the corner is not definitely known to the author. The following is, however, a plausible explanation: in the pass under discussion, the reduction in the flanges (38 per cent) is slightly greater than the reduction in the web (35 per cent). The excess compression in the flanges causes in them a tendency to spread. But the spreading is prevented, which means that side work is done. In the passes which follow,

the same ratio of reduction cannot be maintained: first, because the flanges would become too thin, and second, because the bent-up position of the flanges does not allow of heavy reductions. Therefore, the extra material left in the corners in the present pass "comes in handy" in the finishing pass, and in those immediately ahead of that latter pass, as explained in connection with Fig. 240.

In Fig. 242, the pass is filled nicely. No fin is produced, in spite of the side work. This is largely due to the slope and chamfer at the edge of the flange. (See Vol. I, Fig. 97.)

The method of rolling exemplified by Fig. 242 has the great advantage that side work is done on or against inclined surfaces which can be dressed, after wear has occurred. In the method of rolling, which is exemplified by Fig. 240 and by Fig. 236, that is not the case.

Although the method shown in Fig. 239 offers several advantages, the beam rolling method of Fig. 237 is today employed almost universally for standard channels, because it requires the smallest number of rolls, and because the first roughing passes are identical with those used for I-beams. In the rolling of large channels, the same beam blank serves for channels and I-beams. The first roughing pass (cutting into a rectangular billet) will be discussed under I-beams.

A good set of passes using the roughing beam (or temporary flange) method is shown in Fig. 243. The illustration is so complete that very little comment is needed. The effects of the live pass and of the dead hole are very noticeable. The large radii in the corners, to prevent fins, are also evident. Experienced roll designers emphasize the necessity of the shallow projection (triangular corner) opposite the flanges in pass No. 8, which is the leader, if a square back and sharp corners are desired.

It will be observed that the reductions of web and flanges are very nearly equal in the last two passes, from the values given in Table XXIII. The usual intention is to reduce the flange slightly more than the web, thereby producing a condition of tension in the web. Because the flanges, being thicker than the web, undergo greater contraction during cooling, the stretch condition of the hot web is removed during cooling.

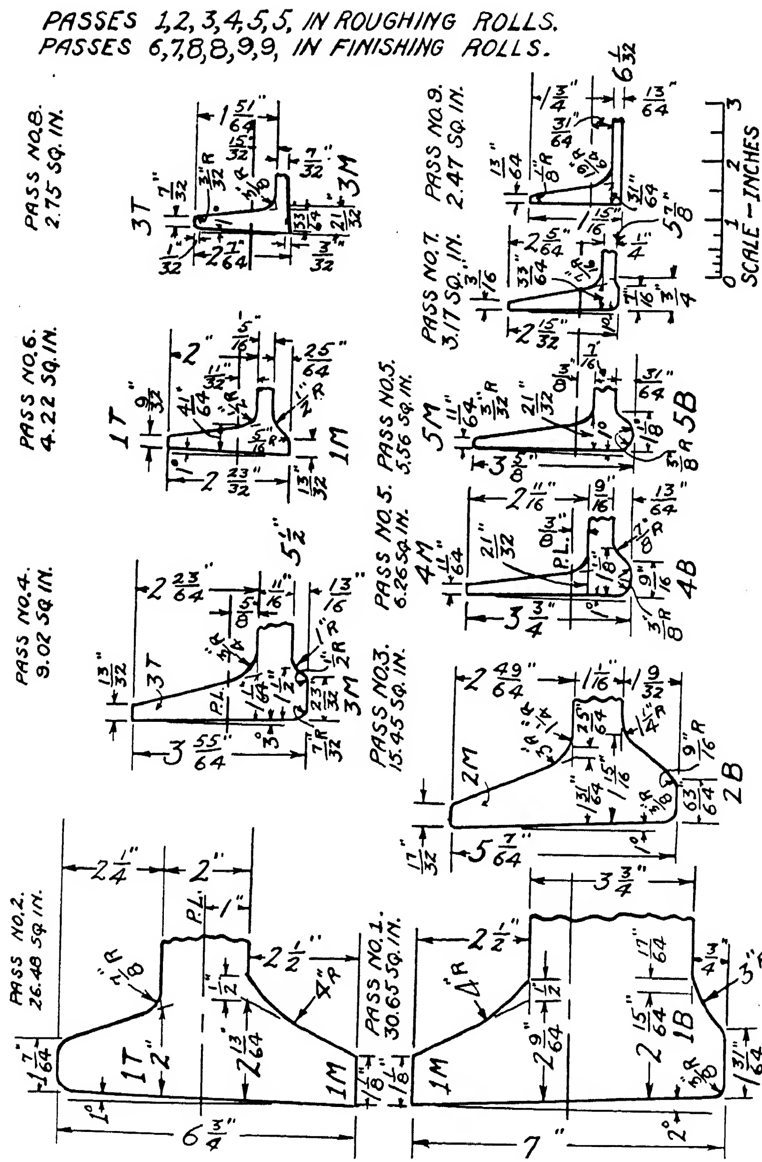

PASSES 1,2,3,4,5,5, IN ROUGHING ROLLS.
PASSES 6,7,8,8,9,9, IN FINISHING ROLLS.
PASS NO.8. 2.75 SQ. IN.
PASS NO.6. 4.22 SQ. IN.
PASS NO.4. 9.02 SQ. IN.
PASS NO.2. 26.48 SQ. IN.
PASS NO.9. 2.47 SQ. IN.
PASS NO.7. 3.17 SQ. IN.
PASS NO.5. 5.56 SQ. IN.
PASS NO.5. 6.26 SQ. IN.
PASS NO.3. 15.45 SQ. IN.
PASS NO.1. 30.65 SQ. IN.
SCALE – INCHES

Fig. 243

TABLE XXIII

Pass No.	Flange Area, square inches	Web Area, square inches	Draft, square inches: Flange	Draft, square inches: Web	Reduction, per cent: Flange	Reduction, per cent: Web	Nominal Reduct of Web, per cent	Total Area, square inches	Total Draft, square inches	Total Reduction per cent
9	1.36	1.11	0.16	0.12	10.5	9.8	7.2	2.47	0.28	10.2
8	1.52	1.23	0.28	0.14	15.5	10.2	12.5	2.75	0.42	13.3
7	1.80	1.37	0.80	0.25	30.6	15.4	20.0	3.17	1.05	24.9
6	2.60	1.62	0.66	0.68	20.2	29.6	28.5	4.22	1.34	24.2
5 b	3.26	2.30	2.24	1.22	40.5	34.5	36.5	5.56	3.46	38.4
5 a	3.46	2.80	2.04	0.72	37.0	20.4	18.2	6.26	2.76	30.6
4	5.50	3.52	4.78	1.65	46.5	32.0	35.4	9.02	6.43	41.6
3	10.28	5.17	...	...	...	...	...	...	...	...

The significance of these values should not be overestimated, for the reason that they are based upon a definitely assumed boundary between each flange and the web. Actually of course, the material in the fillet between web and flange is compelled to flow in both directions; and while a dividing line probably exists, its exact location in any one pass is very difficult to determine, particularly when the fillet has a large radius.

Fig. 244

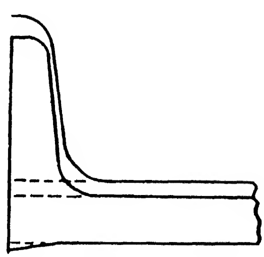


Fig. 245

Any calculations, such as those of Table XXIII, which involve an arbitrarily assumed boundary, should be accompanied

by a statement of the assumption. The division in this case between the flange and the web was made as shown in Fig. 244.

For the sake of simplicity, some roll designers consider the web as being of uniform thickness across the entire width of the section, as shown in Fig. 245, while the remainder of the section is assumed to be the flange. If exactly proportional reductions are used in all parts of the section, the choice of different boundary conditions will not affect the proportionality; consequently the choice of boundary may then be a matter of convenience.

As previously stated, channels with deep flanges are rolled by the method indicated in Fig. 239. To this statement may be added the fact that channels with parallel flanges and with square roots are rolled by the same method, see below.

To avoid chilling of the web by water, channels should be rolled with the flanges down. To allow better riding on the table rollers, channels should be rolled with the flanges up. The latter method is preferred in the United States, probably because the temporary flanges hold the water anyhow.

In the finishing pass, the parting should lie at the end of the flanges, and not at the root (that is to say, at the web), for the sake of easy delivery. Furthermore, a sharp corner is required at the corner (which is not easily obtained at the parting), while a slight rounding, while not desirable, is permissible at the ends of the flanges.

For easy delivery, the wedge angle of the pass is kept as great as feasible. It becomes smaller and smaller as the finishing pass is approached, as indicated in Fig. 246. Theoretically it should become zero (parallel walls) in the finishing pass. However, it is often possible to use a slight inclination on the outside walls in finishing passes for channels, because the flanges draw together slightly while cooling. This is probably due to the fact that the fillets between flanges and web have less radiating surface, in comparison to the thickness of the section, than any other part of the channel; and that the fillets are consequently hotter when finished and undergo greater contraction while cooling than the rest of the section.

The angle or inclination at the inner edge of the flanges of standard channels, rails, I-beams was determined in conferences between structural engineers and steel rollers. The engineers prefer almost parallel flanges, while the roller prefers a wedge, for ease of rolling. The angles differ, and are not the same in the United States, England, and Germany, for instance. In the United States the sidewall inclination of standard channels is approximately 9 degrees, while in Germany this inclination is 4½ degrees. In Belgian practice the inclination varies from zero to 7.5 degrees. If the rolls are kept smooth and free from

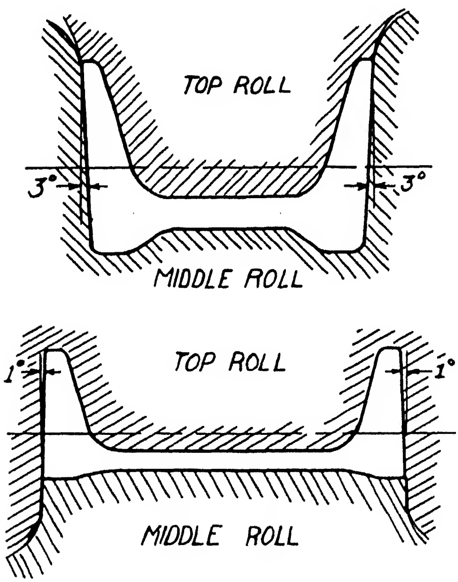


Fig. 246

pitting, smaller angles can be used, but we must stick to the standard angles for standard structural shapes. For other purposes we can use parallel flanges and square roots. A set of passes for such a channel is shown in Fig. 247, which was adapted from "Piron",* a Belgian author on Roll Design.

*"Traite Pratique de Trace des Cannelures pour Cylindres de Laminoirs", par Emile Piron, Maison d'Edition A. de Boecke, Rue Royale, Bruxelles.

In channels, as in all structural shapes, different thicknesses are required for a given size of section. In channels such variation can be obtained either by setting the rolls farther apart, or by using different leaders and finishing passes. As a rule, the former method is used. In that case, the reductions of flanges and of web are not proportional. For that reason, the method is limited to moderate changes of thickness.

I-Beams

I-beams are the most efficient and most important shape in the structural business, and at the same time, one of the most

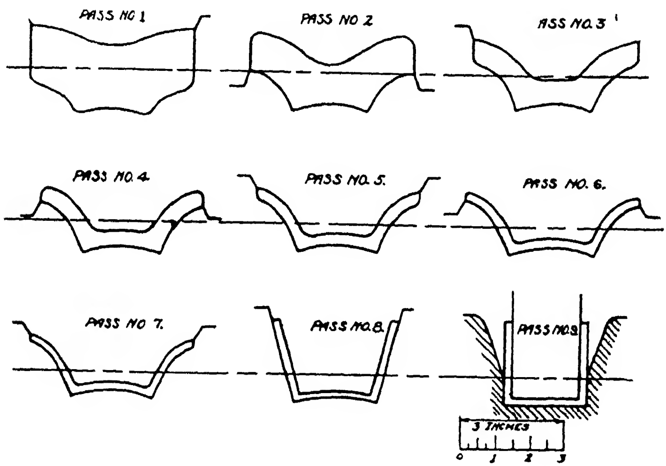


Fig. 247

difficult shapes in rolling. In an attempt to overcome the difficulties, long experience has taught us what we can roll successfully, and also what we cannot roll. The characteristic features of I-beams are the deep flanges on both sides of a thin web. These features prevent edging, and also prevent flat rolling with final bending up by the butterfly method. The absolute (not relative) width of the beam, or length of flanges very largely decides the method of rolling to be employed.

The size of the beam, that is to say the depth of the web, also has an influence on the method of rolling as is explained below.

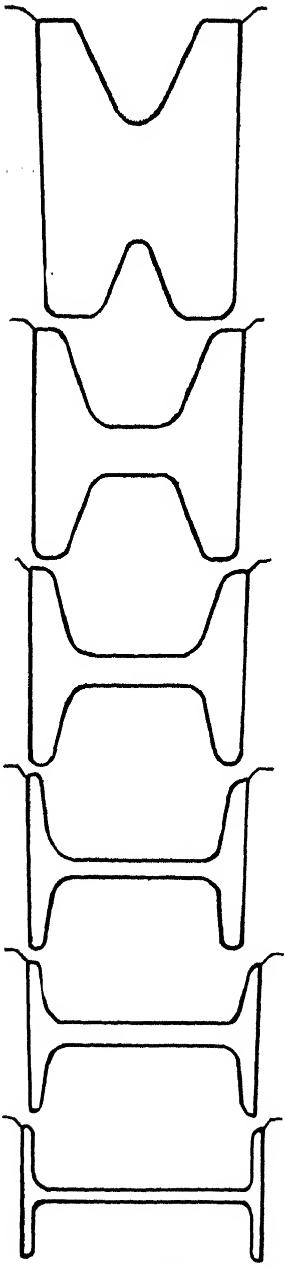


Fig. 248

NOTE:
Some intermediate passes have been omitted from these illustrations

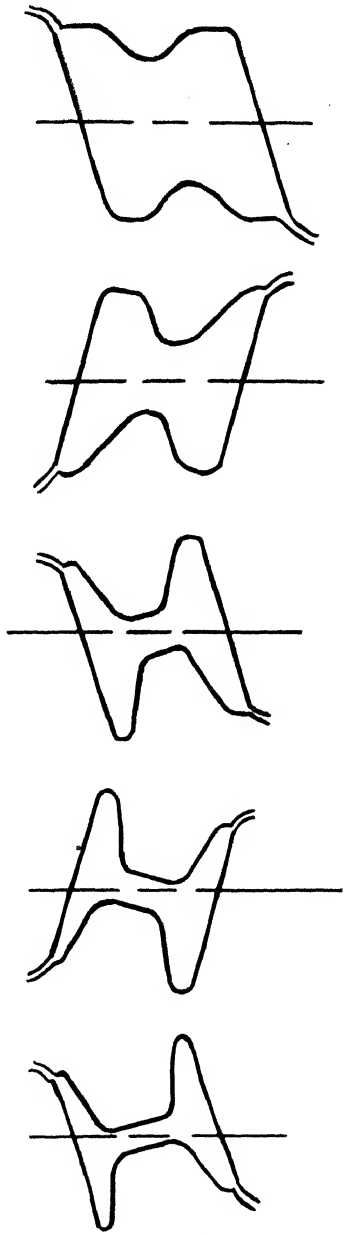


Fig. 249

Methods of Rolling

In the explanation of the various methods of rolling, a few characteristic passes are given for each method, with omission of intermediate passes.

1. Flat rolling, called the beam roughing method, see Fig. 248. It consists in cutting into the center top and bottom and gradually widening the cut. The web remains horizontal.

2. Diagonal rolling, with a certain amount of slabbing action, see Fig. 249. The web is alternately tilted right side up and left side up.

3. The "Slick" method, Fig. 250, in which the web is bent up and down alternately.

4. The truly diagonal method, Fig. 251, in which a square on edge is transformed into a star and then bent into an I-shape.

These four methods are carried out in either two-high or three-high mills.

5. Rolling in a universal beam mill, also known as the "Grey" method. See Fig. 252.

As previously mentioned, the absolute width of the flanges has a decisive influence upon the method to be selected. The flanges of standard I-beams in the United States have a taper of 16.8 per cent. In Germany the inclination of flanges of standard I-beams is 14 per cent. On the basis of a flange thickness of 5/16 inch at the tip of the flange, the thickness of a flange $4\frac{1}{8}$ inches long will be $(5/16 + 0.168 \times 4\frac{1}{8}) = 1$ inch; for a flange 10 inches long the thickness at the root would be $5/16 + 1.68$ which equals about 2 inches. This thickness is so great compared to 5/16 inch at the tip and to an economical thickness of web that the beam becomes impossible. We can deliver a straight beam of such dimensions to the cooling bed, but not from the cooling bed, because temperature strains warp it. The thin parts cool first and are buckled later by the contraction of the thick parts.

Wide flanges require a small taper, which fact eliminates methods Nos. 1 and 4. Methods Nos. 2 and 3 can be used with flange tapers as low as 5 per cent, and can even be used with parallel flanges, but only with difficulty.

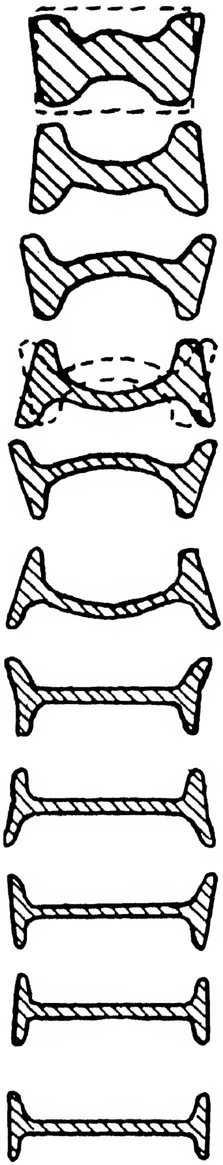


Fig. 250

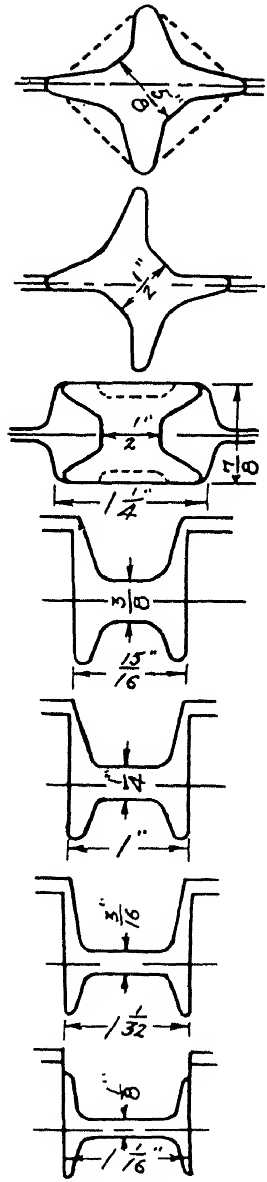


Fig. 251

While wide flanged beams can be rolled by methods 2 and 3, they are, in the United States, rolled exclusively by method No. 5 (universal mill), because of much lower cost per ton,

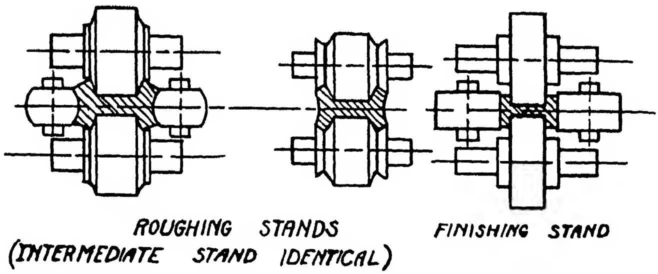


Fig. 252

and because of the ease with which flange weight can be varied without variation of thickness of web. Methods Nos. 2 and 3 require a different set of rolls for each new thickness of flanges. Standard I-beams have a maximum flange width of 8 inches. They are commonly rolled by method No. 1, although works possessing a universal mill frequently roll standard beams in the universal mill and claim a substantial saving due to lower roll cost.

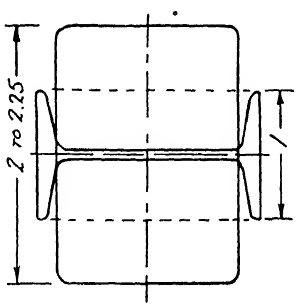


Fig. 253

When rolling wide flanged beams in a universal mill, the width of the beam (length of flanges) is limited only by the size of the ingot (and the size of the mill).

Method No. 1: (Flat rolling or beam roughing method). For small standard beams (up to about 8 inches) the rolling

starts with a rectangular billet or bloom, the depth of which is slightly more than twice the width of the beam, see Fig. 253. For beams which are very deep, compared to the width of the flanges, the ratio is greater than 2.25. For large I-beams, part of the cutting-in must be done in the blooming mill, which, in that case, rolls beam blanks.

To prevent excessive pulling down of the flanges, the cutting-in must compress only a small part of the section, as shown in Fig. 254. The reasons for the pulling down were explained in Vol. I, page 125.

Cutting-in should be done in a closed pass for this reason: The heavily compressed center part cannot elongate, because

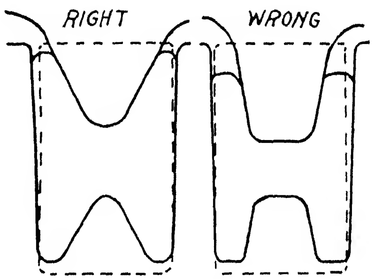


Fig. 254

the larger not compressed sides prevent elongation. The particles must, therefore, migrate from the center to the sides, thereby causing bulging (in an open pass) or even a fin.

After "cutting-in", the reductions are limited either by the diameter of the mill (strength of rolls and roll spring), or by conditions at entrance of the bar into the pass. The situation depicted in Fig. 255 must not occur.

Since the flange lying in the dead hole can be compressed but very little, and the flange lying in the live pass is compressed as much as possible, strain is caused in the bar, due to one-sided deformation. These strains are, however, not cumulative, but are held within narrow bounds, because each flange lies alternately in a live pass and in a dead hole.

For this reason, I-beams are particularly well suited to being rolled in three-high mills and are rolled on such mills in the

United States. In Europe they are frequently rolled in two-high reversing mills. In that case, the bar must either be turned over after each pass, or else be transferred to another stand in which live pass and dead hole are interchanged.

Reductions become smaller towards the finishing pass, because the smallness of the taper of the flange allows less and less side work to be done (see Vol. I, pages 148-150). The gradual decrease of the reduction works out well in conjunction with the fact that the bar becomes colder, because a heavy reduction of a cold bar would result in excessive roll wear. If the roll diameter is rather small, more passes must be used, and the length of the bar must be reduced, to prevent excessive cooling.

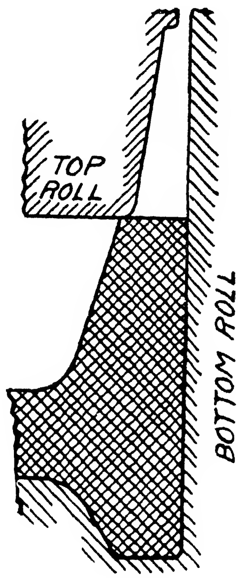


Fig. 255

Towards the finishing end care must be taken that the reduction (in per cent) of flanges and of web are very nearly alike. It is customary to reduce the flanges slightly more than the web for the purpose of putting compression into the flanges and tension into the web, particularly so if the average thickness of the flanges exceeds that of the web. The designer has very

little leeway in this respect. If he compresses the web too much, it tends to buckle, and the spreading jams the beam in the roll. If he compresses the flanges too much, the flanges do not fill well (become wavy in outline), and the cross-tension of the web pinches the roll. In some mills, the web is left slightly thicker near the ends than in the center, for the purpose of preventing the beam from pinching against the rolls between the flanges.

After these explanations, the study of a set of I-beam passes is appropriate. A good set is shown in Fig. 256, Plate III. All dimensions, location of passes in rolls, and reductions are given, and need no comment. As in former drawings of passes, it is not expected to have the flanges fill the sharp corners of the live pass, except in the finishing pass. It must be repeated that change of roll diameter, composition or temperature of bar, roughness of rolls will require modifications of a set of passes which is very successful for one given set of conditions. In the leader and in the finishing pass the following reductions are used in flanges and web:

	Reduction, per cent	
	Flanges	Web
Leader	11.1	8.3
Finishing pass	5.7	5.3

The weight, cross section, section modulus, and moment of inertia of a standard I-beam are varied by pulling the rolls apart. However, the change of roll adjustment for rolling I-beams of different weight is a makeshift method, made necessary by economic reasons, and is limited to very small variations in thickness, because thickness of the web grows faster as a result of the adjustment, than the thickness of the flange.

The compression relations in the rolling of I-beams becomes clear from a section-by-section analysis of one pass. Such an analysis is shown by Fig. 257. The fact that the flange is compressed ahead of the web is quite apparent.

This difference in length of time of compression explains the offsetting of the pitch line which is very noticeable in Fig.

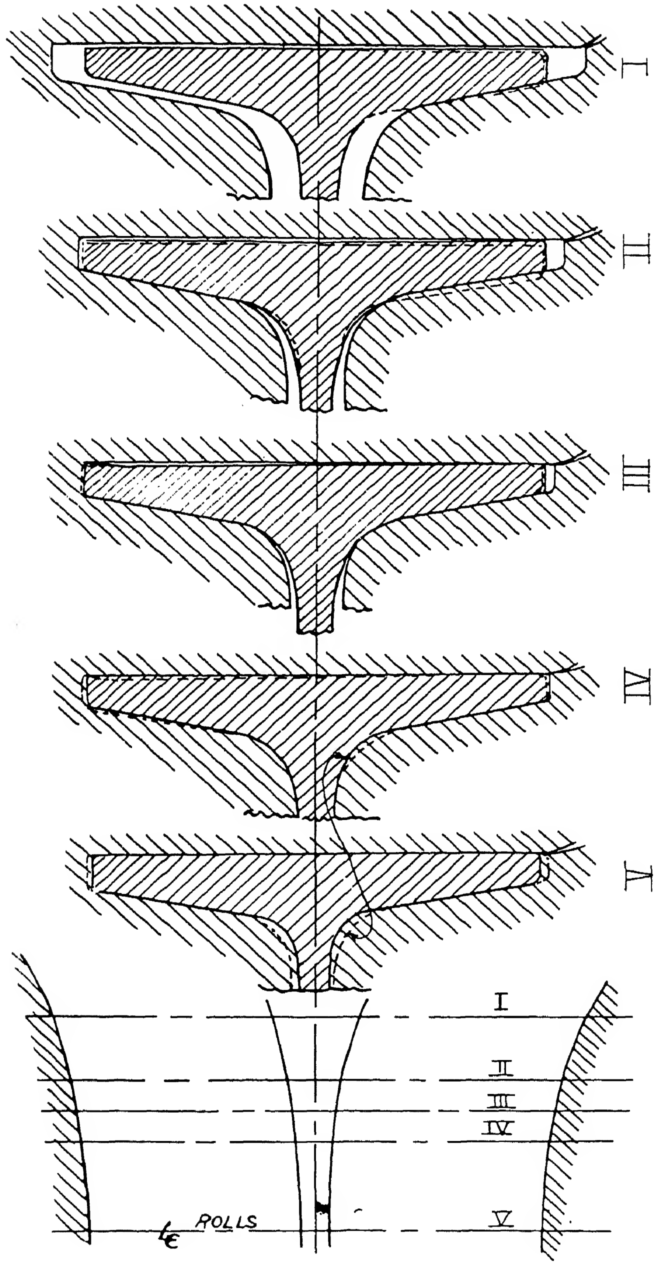


Fig. 257

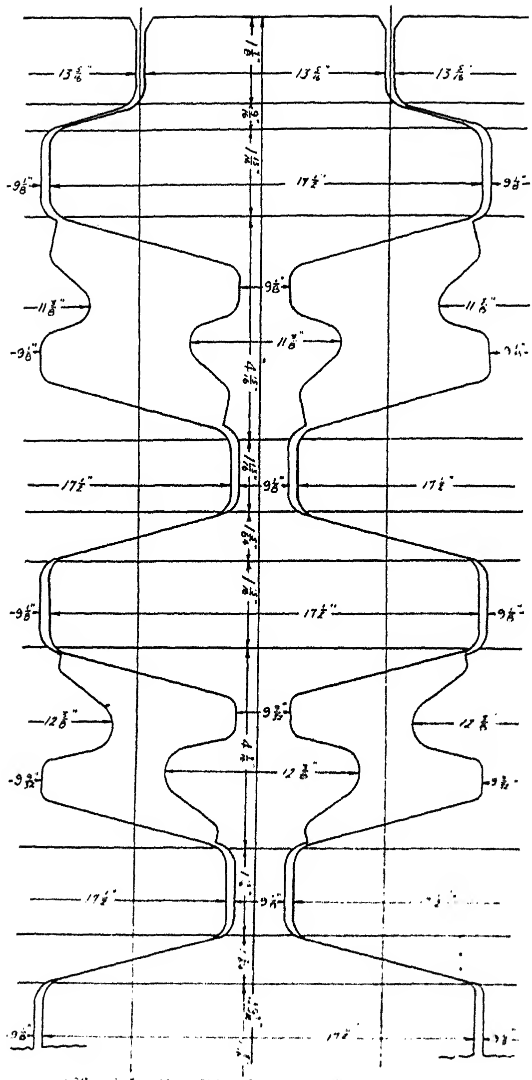


Fig. 258-A

256. In Vol. I it is shown that the pitch line should lie at the end of the effective radius. But more compression work is done in the live pass than in the dead hole; consequently, the pitch line should be shifted toward the live pass. This fact works

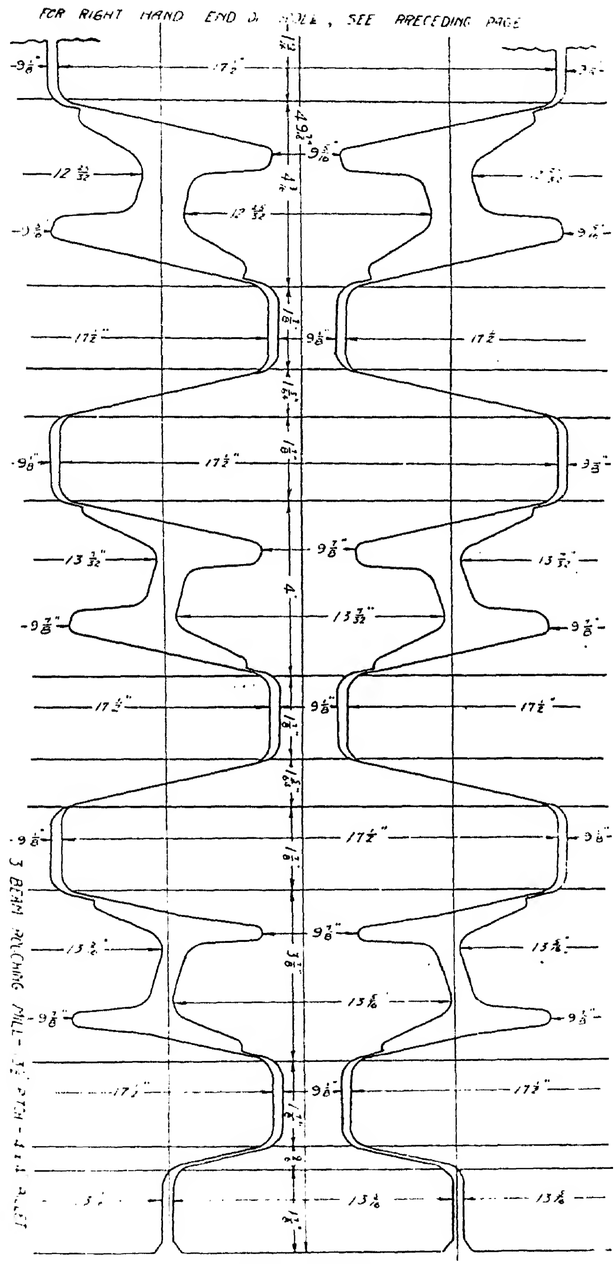

FOR RIGHT HAND END OF ROLLS, SEE PRECEDING PAGE
3 BEAM ROUGHING MILL

Fig. 258-B

out well for the strength of the middle roll, which wears more rapidly than the outer rolls and needs more redressing. Shifting the pitch line reduces the depth to which the middle roll is cut.

Diagonal Rolling

This method permits slabbing action, and, in consequence, heavier reductions and smaller flange tapers. On the other hand, the collars necessitate a lot of waste length along the rolls. The method is useful for small and medium-sized beams and, as previously stated, is used for wide flange beams if no universal mill is available. It cannot be used in the rolling of large beams, because the rolls would need to be too deeply cut; it must be remembered that large beams are rolled on comparatively small rolls.

If standard beams are to be rolled on the diagonal, the last few passes must not be diagonal, but horizontal, to permit variation of cross section by adjustment of center distance between rolls.

Fig. 258 illustrates diagonal roughing passes for a small I-beam, and Fig. 259, Plate IV, illustrates diagonal passes for an H-beam (which latter is an I-beam with wide flanges).

The illustrations contain all the information and speak for themselves.

Rolling mill plants without a universal beam mill have used the method of Fig. 259 for beams with flanges up to 12 inches wide. The inclination of the flanges must be very small (in other words: the flanges must have almost parallel walls), if the beam is to stay straight on the cooling bed. As previously mentioned, flanges with almost parallel walls call for very clean and smooth rolls.

Slick Method

This method allows just as heavy reductions as the diagonal method, without the collar complications. It was, however, never adopted to any extent, and has been abandoned, not only because of a patent monopoly, but also because the method has

no advantages sufficient to compensate for the high roll cost which its use involved.

The Truly Diagonal Method

The truly diagonal method needs no comment, because Fig. 251 is quite clear. It is limited to the rolling of very small beams.

Rolling in the Universal Mill

This method concerns the roll designer to a limited extent only, because reductions of web and of flanges are independently adjustable by the roller. All three arrangements shown in Fig. 260 have been used successfully. The rolls wear and pit heavily at the places marked *A* and *B;* at *A* because the metal flows around the corner; at *B* because spreading action forces the metal against this part of the vertical roll.

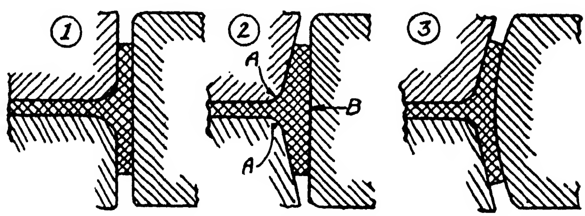


Fig. 260

The beam blank passes through a set of two rolls, with the following action: *Going*: (a) compression of web and of flanges; (b) work on edges of flanges. *Return*: compression of web and flanges. This cycle is repeated until the desired thicknesses have been obtained.

Arrangement (1) of Fig. 260 has the highest roll cost, because any wear beyond the tolerance means that the horizontal rolls must be discarded and can only be used for the next smaller size of beam. Arrangement (2) is better, but does not furnish a beam with parallel flanges. Arrangement (3) is the most advantageous. (3) may be used as a leader for (1), but (2) may not.

Light-Weight I-Beams (Thin Walls)

If extra-light I-beams with thin walls are rolled, the proportions of Fig. 253 do not hold. In the I-beam of Fig. 261, cutting-in and gradual widening of the cut causes so much pulling down of the flanges that a bloom much deeper than 2¼ times the flange width is required. The depth ratio may have to be 4 or even 6, depending upon the proportions of the beam, and the number of passes is correspondingly increased.

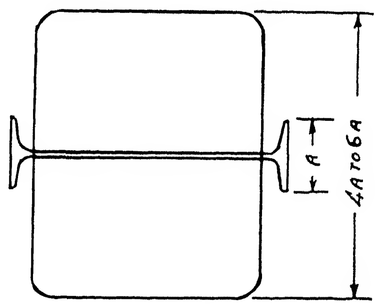


Fig. 261

Diagonal rolling with a substantial inclination of the beam to obtain quick reductions is impossible for deep, light beams, because the rolls would be too deeply cut.

In order to overcome the difficulties caused by the large number of passes required for the production of a deep thin beam, Mr. Rendleman introduced the method of rolling beams with a corrugated web and with gradual stretching (by lateral tension and direct compression) of the web.

Fig. 262 clearly indicates the method. The new feature of this process consists in producing two complete corrugations and in rapidly widening the beam by straightening out the corrugations. This action is made possible not by direct compression, but rather by the combination of direct compression and lateral pulling due to horizontal forces against the inside of the flanges.

A study of the illustration reveals the fact that the lateral pulling due to internal sidework against the flanges has been

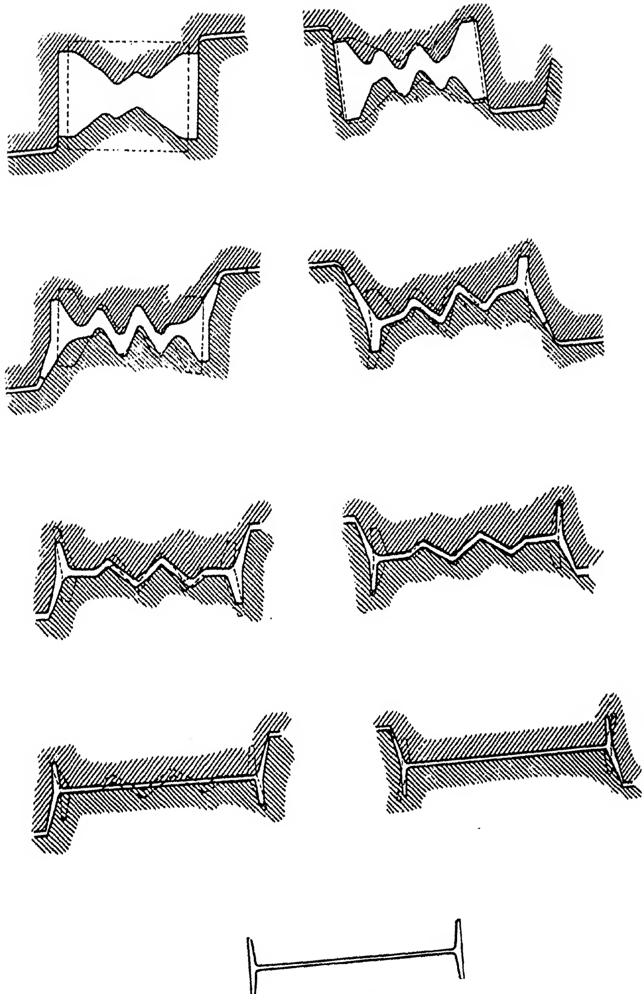


Fig. 262

carried to the limit of what is compatible with safe entering of the bar.

This method can be used successfully only because of great lateral tension which results from the forces exerted against the flanges. Attempts to roll other sections in this manner have failed whenever there has been insufficient lateral

tension, because laps occur without that tension. Tests of beams which have been rolled by this method show higher values of tensile strength and elastic limit than are common in hot rolled mild steel.

Tee Shapes

Small T-sections up to 3½ inch x 3½ inch are very commonly (and 4 inch x 4 inch tees occasionally) rolled and used; whereas large T-sections are not favored by roll designers and are, in structural work, replaced by two angles back to back. The differences in size of T-sections make necessary the consideration of the following features:

1. In small tees the thickness of the metal is great compared to the overall dimensions of the T, whereas in large T-sections the wall thickness is small compared to the over-all dimensions.

2. Small tees are rolled on comparatively large mills, which allow heavy reductions, while large tees are rolled on comparatively small mills.

3. Tee sections require at least one pass in which the stem extends straight into the roll, cutting the latter deeply and weakening it.

4. The deep stem offers difficulties in being released from the roll.

Small Tees

Small and medium tees are rolled by entering a square on the diagonal into a bell pass, as shown by passes *a* and *b* of Fig. 263. The bar from this pass is compressed without edging into a flat pass, as shown by pass *c* of Fig. 263. This embryo tee is then edged, and the stem-to-be is given considerable draft, with comparatively small reduction of the table. This unequal distribution of draft causes the stem to spread enormously. It cannot go into length because it is held back by the table. As a matter of fact, the table seldom fills the pass, but is crippled. Fig. 264 shows the section in question before entering and after the pas-

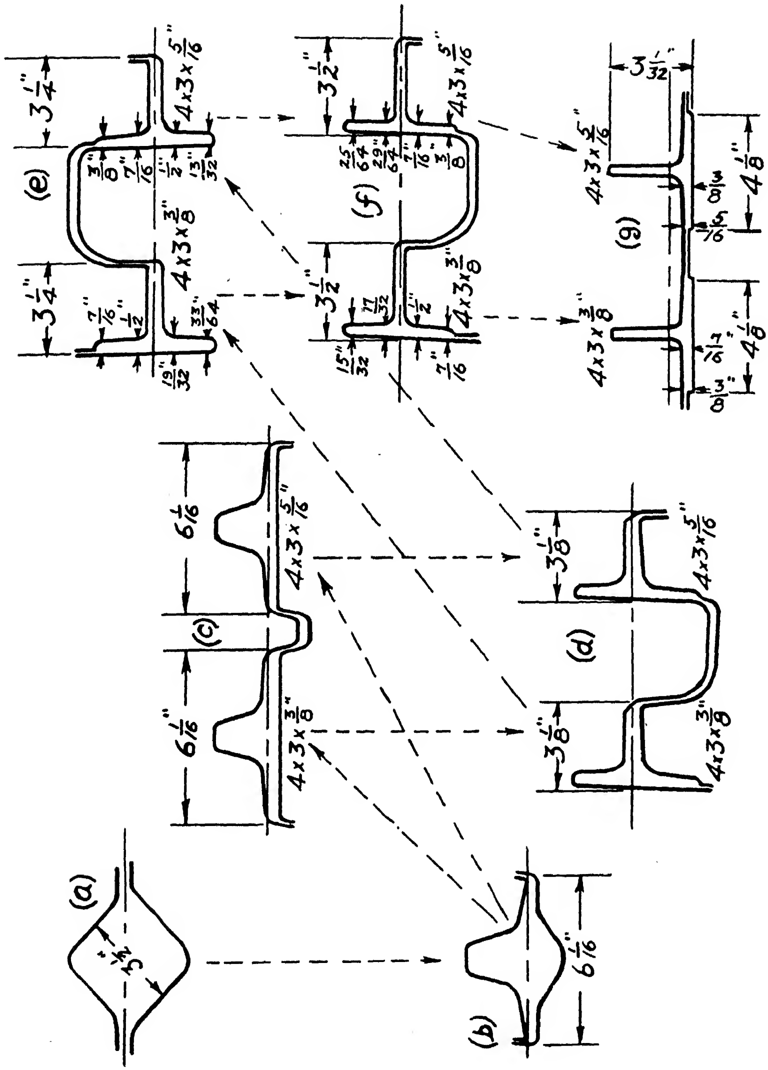


Fig. 263

sage. The section outlines shown in this illustration were taken from the cobble illustrated by Figs. 67 and 68 of Vol. 1.

The edging pass illustrated by Fig. 264 is characteristic in the quick rolling of tees, but is viewed with disfavor by many

roll designers and rollers, and is avoided by them. Because of the unequal reduction, the bar bears against the delivery guide with enormous force, and cobbles are frequent on the delivery side of the pass. The end of the bar also "fishtails" badly, and is difficult to enter into the next pass.

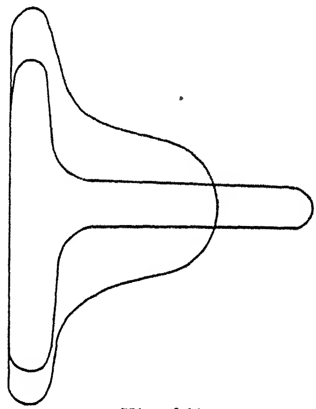
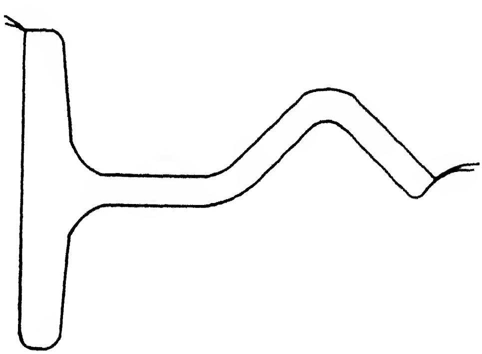


Fig. 264

From the edging pass the bar enters into the finishing pass. Hence, only four passes are required for small tees. Medium tees require five to eight passes. In medium sized tees, two passes are used for compressing and lengthening the stem. If the stem of the T is to be extra long, the edging pass is given the shape of Fig. 265. The subsequent pass in the same direction flattens and lengthens the stem.



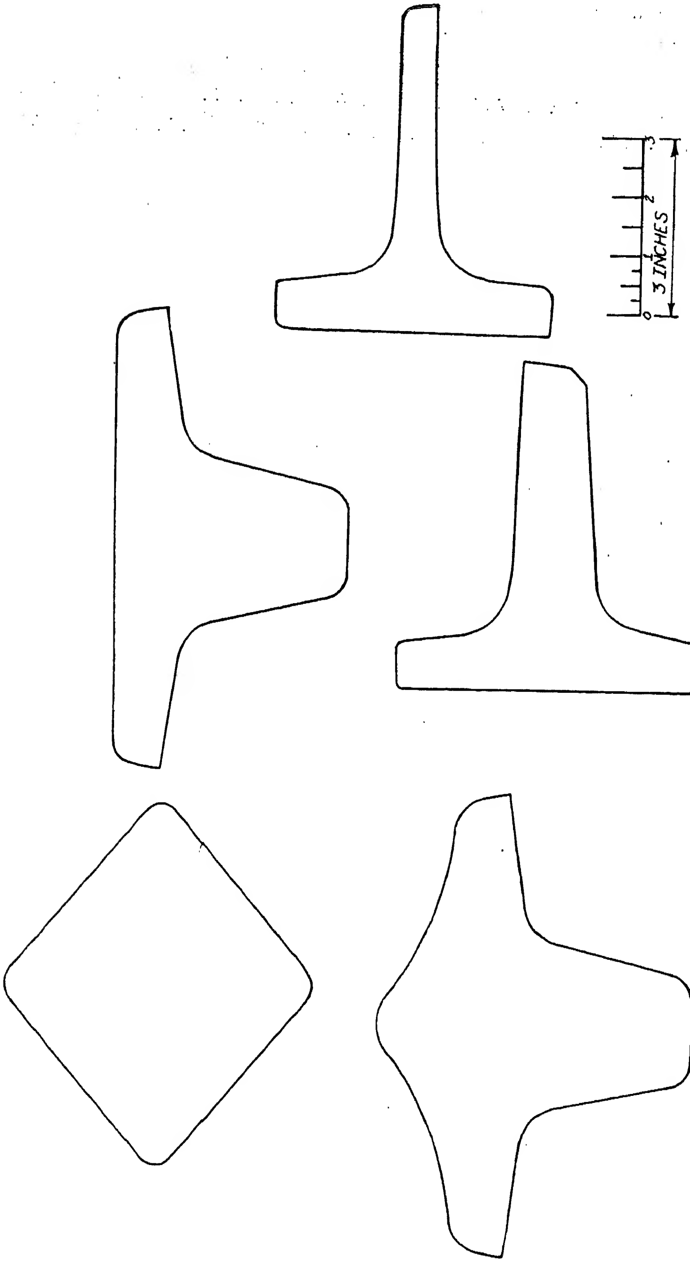


Fig. 266

The characteristic passes for a 4 inch x 4 inch tee are shown in Fig. 266 for the benefit of those who may wish to roll a fairly large T-section. Of interest is the amount of spreading in the bell pass and in the edging pass. It will be noted that the reduction and spreading are more conservative than those of Fig. 264.

1¼ inch x 1¼ inch tees are rolled on a 10 inch or 12 inch mill.

4 inch x 3 inch tees are rolled on a 16 inch or 18-inch mill.

While the above described method is commonly used, it is by no means universal. Fig. 267 shows a method (for 2 x 2 x 3/16 or ¼-inch tees) in which edging occurs after each pass. The method is very clear and needs no comment, with the possible exception of drawing attention to the different settings (indicated by dotted lines) of the mills for the two different thicknesses. In those passes in which the table lies flat between the rolls, great care must be taken to distribute the reduction properly between the table and stem. The upsetting reduction of the stem tends to jam it in the groove while the reduction of the table tends to cripple the stem and pull it out of the groove. In these passes no stops are used on the edges of the table, so as to allow free spreading.

The same reasoning applies to the finishing pass. The stem is reduced 10 per cent in length, and a little clearance is left on the sides to prevent jamming. The reduction of thickness of the table is about 30 per cent. The actual reduction is less on account of the spreading. Since the elongation of the table tends to be greater than that of the stem, the latter is lifted out of the groove, but the table tends to hurry ahead, curving the bar downwardly. This effect can be partly counteracted by placing the pitch line low.

If no stops are provided for the table in the finishing pass, the width of the table may vary with changes of temperature in the bar. For very accurate work, a few more passes are added and stops are provided for the table. In that case, the spreading in the finishing pass must be quite small (between 1/32 and 1/16-inch). On account of the small reduction of the table, the stem tends to stick, unless the following expedient is used:

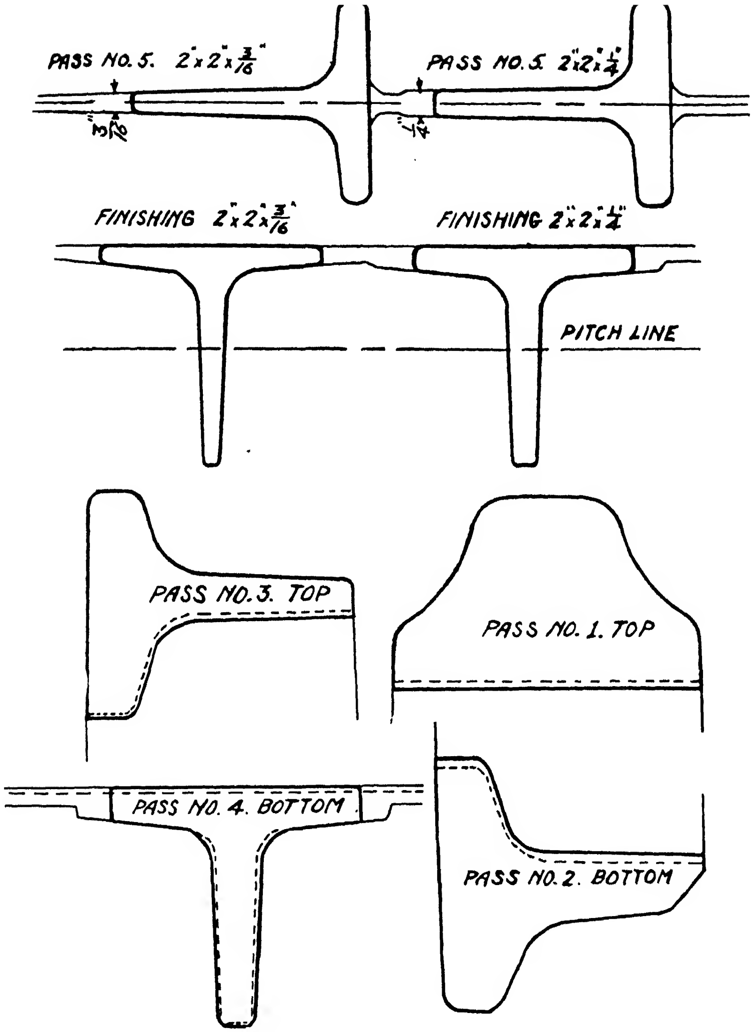


Fig. 267

The table is compressed more heavily near the stem than at the edges. The elongation near the edges is 8 to 10 per cent, and near the stem the reduction may be 40 per cent or even more.

Fig. 268 shows a series of passes for tees of two different

sizes. The reductions in the last four passes are as shown in Table XXIII-A, page 148.

It will be observed that the side of the table which lies in the dead hole of a given pass is not reduced in thickness in that pass. Each side of the table, of course, lies alternately in a dead hole and in a live pass; and because there are three such passes preceding the finishing pass, the table entering the finishing pass is of unequal thickness on the two sides. Consequently, the reduction in the finishing pass is one-sided, which doubtless produces a tendency to curve the bar as it leaves the pass. It will be observed further that, in the finishing pass, the reduction of the table is greater at the edges than near the stem. This is the previously mentioned condition which produces a tendency for the stem to stick in the groove. The groove in this case has been made wide enough to allow 7 to 10 per cent spreading of the stem before the grooves are filled, which is probably a sufficient allowance to offset the sticking tendency. These passes undoubtedly produce satisfactory tees although they do not represent the best practice.

A special type of tee shape contains a bulb at the end of the stem. The method of rolling this section is similar to that of rolling other tees. Fig. 268 illustrates the method.

It is quite evident that the large spreading of the edging pass, Fig. 264, cannot be used in this case. The corresponding pass of Fig. 268 is pass No. 2 into pass No. 3. The increase in width is only 6 per cent. The compression of the table might well have been more.

The bulb is such a hindrance in rolling that 10 passes are required.

The rolling of more complicated T-sections is described under the heading of special sections.

Large Tees

Large T-sections, as previously mentioned, are taboo; if their manufacture is insisted upon, they are rolled from a rectangle which has twice the width of the tee and 1-2/3 times the depth of the stem of the tee. The rectangle is en-

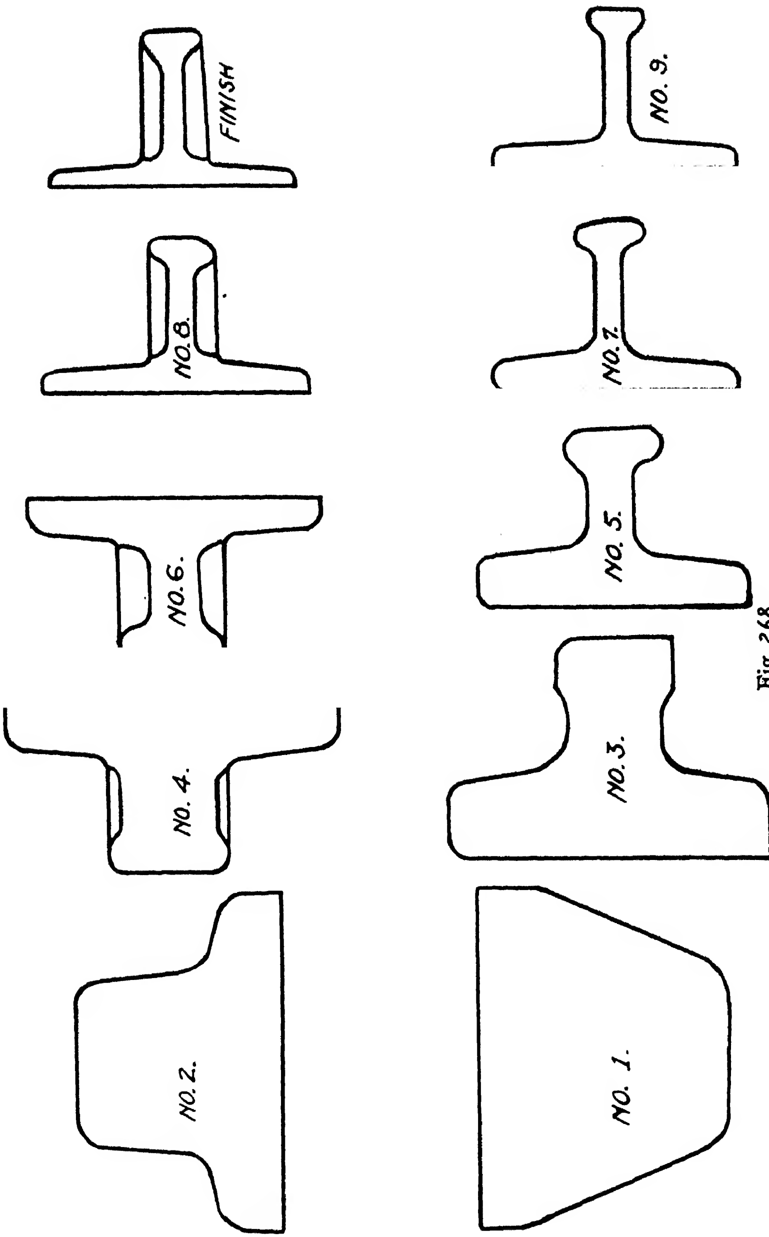


Fig. 268

TABLE XXIII-A

Reductions in Passes of Fig. 263

Per Cent Reduction in Thickness of Table				Per Cent Reduction in Width of table	Per Cent Reduction in Thickness of Stem		Per Cent Reduction in Depth of stem		
Top Side		Bottom Side							
Near stem	At end	Near stem	At end		Near table	At end			
1	2	3	4	5	6	7	8	9	Pass
22.3	25.0	6.2	14.3	24.7	66.0	46.8	....	d	4 × 3 × 5/16 T's
		12.5	7.7	11.0	28.6	18.8	....	e	
17.2	20.0	14.3	16.7	4.5	20.0	23.1	....	f	
			13.3	...	...	...	14.4	g	
23.8	17.7			28.9	63.0	40.0	....	d	4 × 3 × 3/8 T's
		15.8	15.1	9.5	30.4	22.2	....	e	
17.7	20.0	12.5	14.3	4.5	12.5	14.3	....	f	
					...	...	14.4	g	

tered on the narrow side, that is to say, standing up as shown in the first pass of Fig. 269. The reduction on the right and left side of the rectangle is different. This difference of reduction has the effect of curving the bar as it leaves the mill; that is to say it causes the bar to curve toward the side where there is the least reduction. The tendency to curve is partly counteracted by the rolls and by the delivery guide. On account of the heavy pressure between the leaving bar and the delivery guide, the latter wears very rapidly and must be set up quite often. It is evident that the shape of the leaving section will be different from the shape of the pass; because the stretching on one side due to the guide will reduce the section on that side, and the compression on the other side will have a tendency to increase the section on that side. After a few, say four passes, the T-blank which has been produced is edged and both the table and the stem are reduced. After two passes the tee is again edged and is then rolled like any other structural shape; that is to say, with the live pass first at one end of the table and then at the other, and with approximately the same reductions of the table and of the stem.

Rolling T-Sections on the Diagonal

A method of rolling T-sections on the diagonal was described by Geuze on sheets 72 and 73 of his treatise of rolling iron and steel. It is reproduced herewith as Fig. 270. It will be noticed that alternately the table and the stem are "slabbed". This method of rolling is mentioned here as curiosity, rather than as an example worthy of imitation. As a matter of fact, this method of rolling tee sections is very objectionable for the reason that straight delivery of the bar is almost impossible. Collars, or cobbles, accompany this method of rolling to such an extent that its use has been completely abandoned.

Rails

Rails are made of hard steel, and the railroad companies insist upon close tolerances. The characteristic feature of the rail is the combination of a heavy head, deep, thin web, and

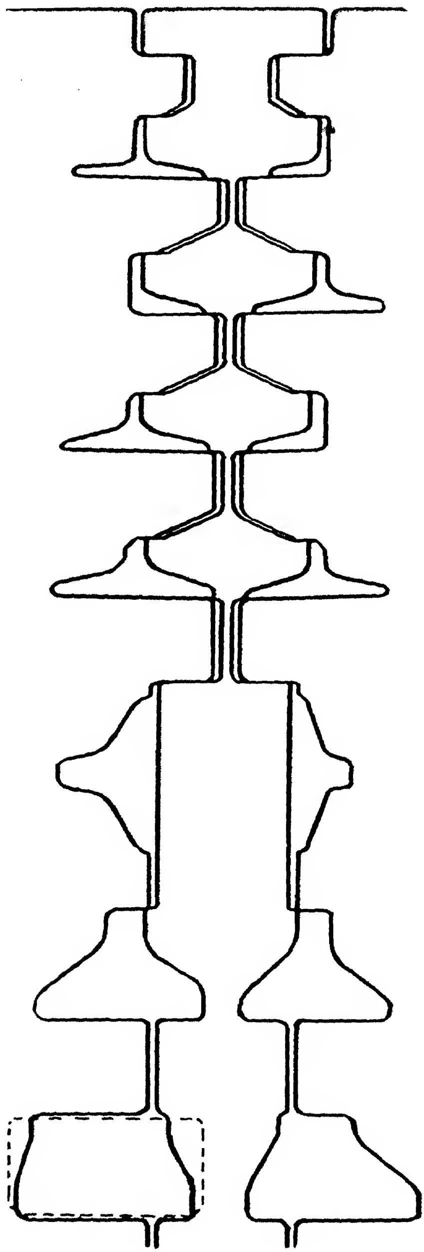


Fig. 269

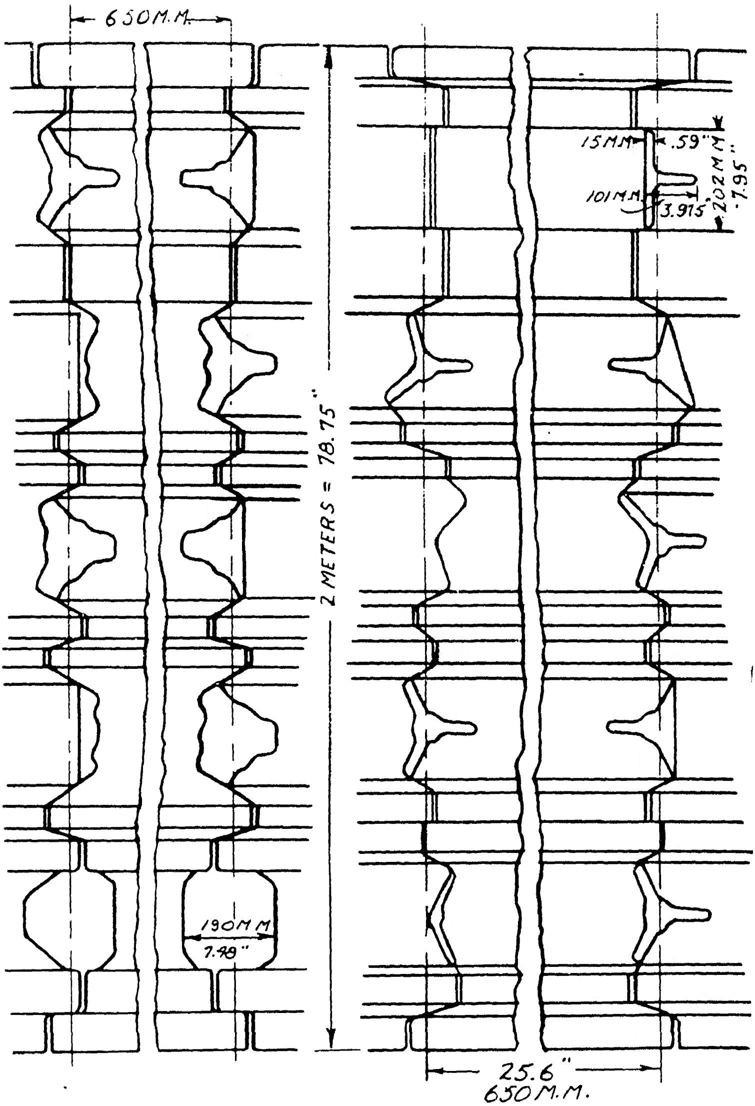


Fig. 270

wide foot (flanges). On account of the uniform and strict specifications issued by the large railroad companies, the methods of rolling have been well standardized. The method

in each country is quite uniform, although the methods vary from country to country.

Methods of Rolling

(1) *The slab-and-edging method.* This method is used almost exclusively in the United States. Fig. 271 illustrates this method. It will be seen that the forming of the foot is begun by a spreading action in the first few passes. After a 90-degree turn, cutting-in occurs (in the same manner as for I-beams).

The difference in width of head and of flange (of the finished rail) makes possible a characteristic edging ("dummy") pass, in which the foot is widened by effective spreading. The spreading is effective, because the compressed area is small compared to the not-compressed area. From here on, the head and flange are worked away in the manner which is known from the previous study of channels and I-beams. For very heavy rails, a second edging or dummy pass is used for compressing the foot flanges.

Due to the effectiveness of this edging pass, the depth of the bloom can be less than twice, say 1.8 times, the width of the foot.

The finishing pass for rails is likewise very characteristic. The pass is split at one side of the foot of the rail and also in

TABLE XXIV

Reductions in Rolling a 125-lb. Rail Section

	Area, square inches				Reduction, per cent			
	Head	Web	Base	Total	Head	Web	Base	Total
1				54.30				
2				43.60				19.70
3				38.20				12.40
4				33.10				13.30
5	11.45	5.53	11.35	28.33				14.40
6	10.00	4.81	9.79	24.60	12.70	13.00	13.75	13.20
7	9.44	4.22	9.31	22.97	5.60	8.20	5.00	6.60
8	8.49	3.78	8.00	20.27	10.00	10.50	14.00	11.50
9	6.27	3.15	6.56	15.98	26.20	16.50	18.00	21.20
10	5.19	2.79	5.27	13.25	17.00	11.50	19.50	17.00
11	4.83	2.57	4.97	12.25	6.95	7.40	8.00	7.55

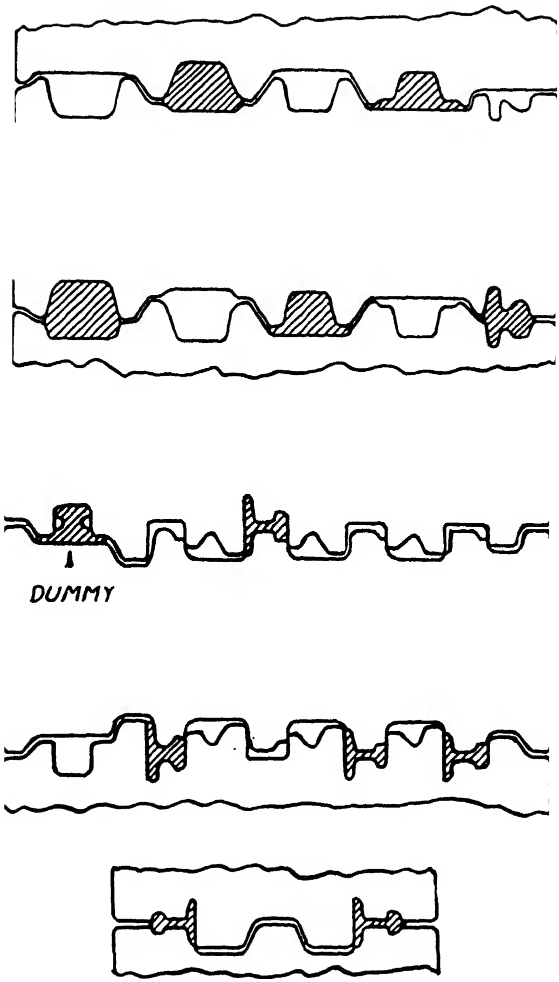


Fig. 271

the center of the head of the rail. In other words, the foot is finished like an I-beam, while the head is finished like a round bar, see Figs. 271 and 273b.

Since tolerances are close, and rail material is hard, at least two finishing passes and two leaders are provided for one set of roughing passes.

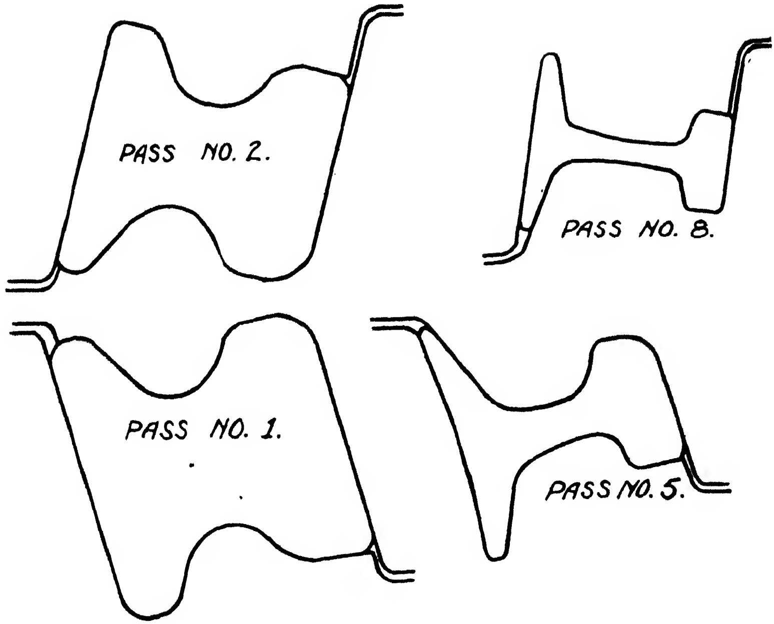


Fig. 272

Depending upon the size of the rail, from nine to eleven passes are needed from bloom to finished section.

The reductions in rolling a 125 pound (to the yard) rail are given in Table XXIV. Division of section into head, web, and base is, of course, not possible in the early passes. The distribution of reductions in the last passes differs from that which is used for I-beams or channels.

(2) *Diagonal method*: The differential reduction between the head and flanges can also be obtained by inclining the section and using a partial slabbing action on the flanges. Fig. 272 illustrates the method.

The outstanding advantage of the diagonal method lies in the ease with which worn rolls can be restored to correct condition. The disadvantage commonly cited against this method lies in the room required by "diagonal plus collar" along the roll axis. However, that increase of length is so small as to be without practical influence. While the diagonal method was originally used for small rails only, it is now used

for even the heaviest sections, provided the mill diameter is large enough. There is no "dummy" pass in the truly diagonal method.

In France and Belgium, the first four passes are rolled on the diagonal. The rest is slab-and-edging. Figs. 273a and 273b illustrate this combination. The reduction of the flanges in pass 5 is particularly noticeable. It results from the fact that the first four passes act as roughing passes for a number of rail sizes, while passes 5 to 9 serve for a light-weight rail of the series.

(3) *Cutting-in and flange bending*: This method, which is illustrated by Fig 274, is described here on account of its originality. It emphasizes the fact that a given section can be rolled in many different ways. The illustration was adapted from "Dehez, Walzenkalibrierungen". Dehez states that this method of rolling can be used only on those mills into which the bloom enters slowly.

This statement is probably correct, for several reasons. The blank entering pass No. 1 must have a tall rectangular section, which does not enter readily unless the speed is low or else the roll diameter is too great for the rest of the passes.

Furthermore, a pass with sidewalls which taper only slightly consumes much power, because of the grinding friction of the side walls. It the rolling is done at very low speed, the compression rate, and the compressive resistance of the steel are low. In consequence, the side pressure (which is a fraction of the direct pressure, see Vol. I, page 153) is also small, whereby the power consumption by side friction is reduced. The reduction of side pressure saves the rolls, because too much side pressure pits them and because pits cause slivers on the bar. Pitting is not permissible, because the specifications of the railroads allow only first-quality rails to be accepted.

Much of the objection to this pass can be overcome by rolling the bloom through a preparatory pass such as is indicated in Fig. 274-a, for the purpose of having contact mainly at the bottom of pass No. 1 of Fig. 274 with contact at the sides only where necessary. This extra pass reduces the friction materially and lengthens the life of the rolls.

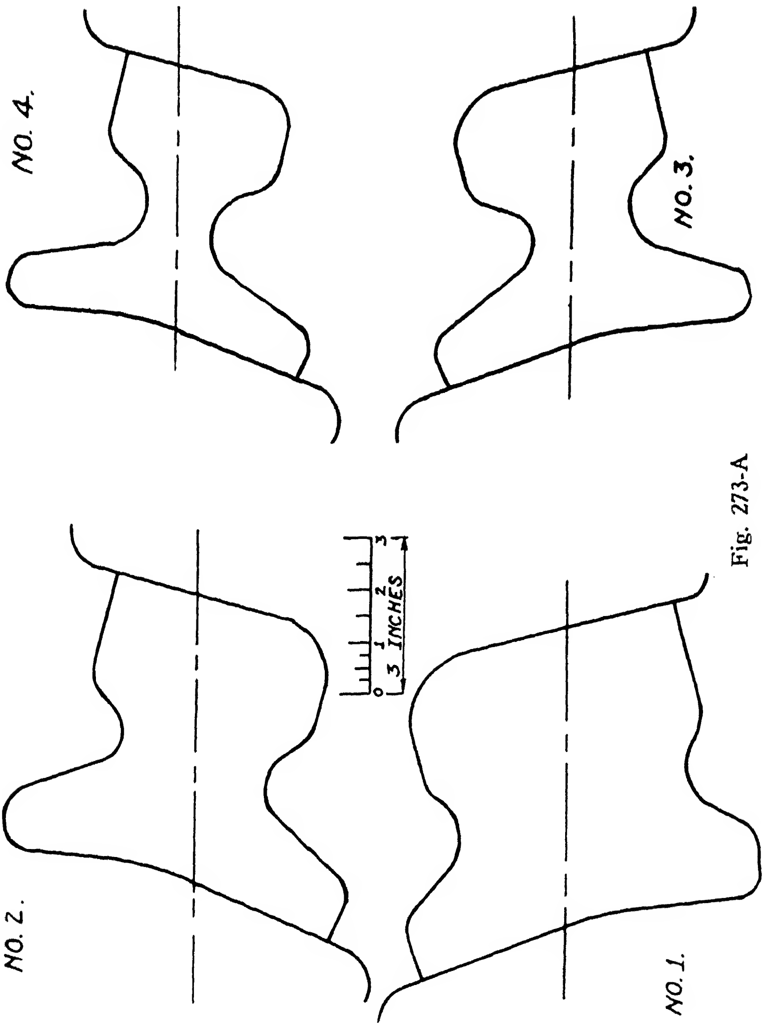


Fig. 273-A

However, this expedient does not remove the necessity for slow entering between small rolls. Most rail mills are of the constant (high) speed three-high type, which would never "bite" a tall bloom. It is, therefore, not surprising to learn that the method shown in Fig. 274 has been adopted in very few places only.

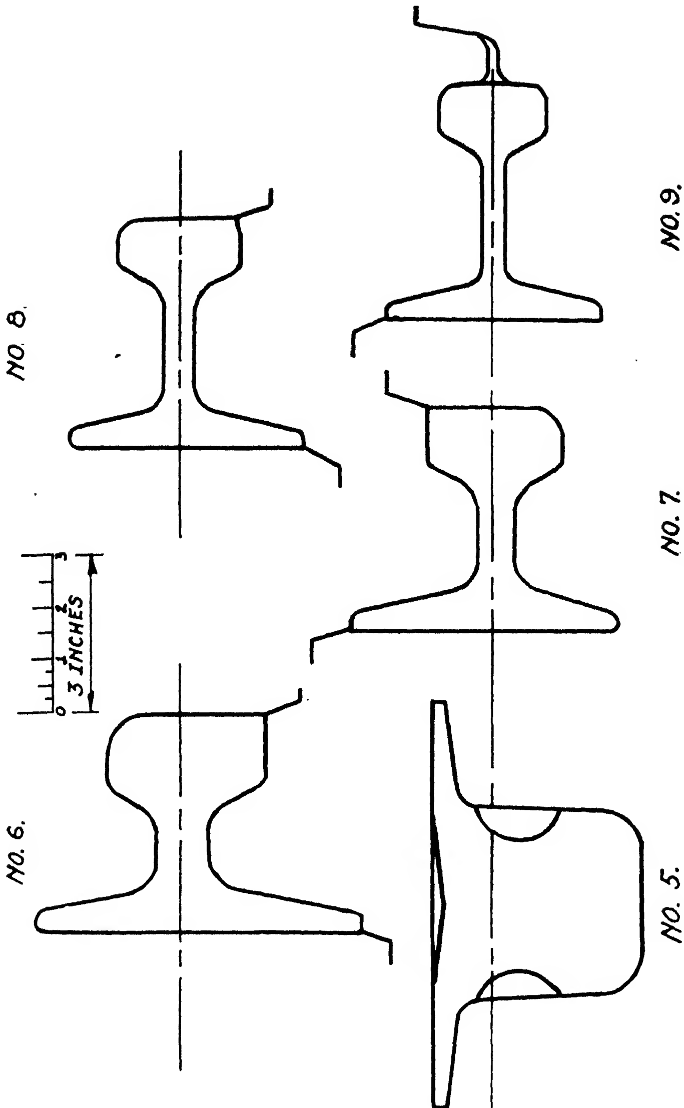
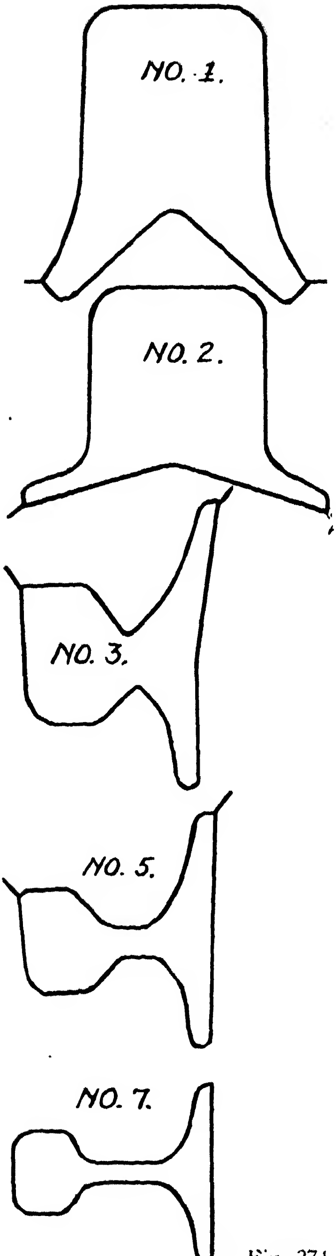


Fig. 273-B

The first two passes form the foot flanges. The third and all following passes consist of cutting-in and gradual working away of the material towards the flanges and the head. This



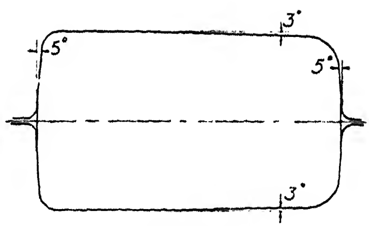


Fig. 274-A

Fig. 274

part of the deformation offers nothing new compared to the previously treated rolling of channels or I-beams.

Characteristic Pass of the Slab-and-Edging Method

Fig. 275 is a section-by-section analysis of an edging pass, in which the rail blank enters into the dummy pass. Compression of the whole section must be very moderate, to prevent buckling of the web. The spreading of the flange is considerable. Even greater spreading of the foot flanges can be obtained, if desired. In the present case the spreading is kept low because the series of passes for this rail section includes two such dummy passes. The illustration is so completely marked that no further comment is necessary.

Cooling of Rails

The very thick head of the rail stays very hot, the thick junction between foot and web stays hot, while the web becomes comparatively cold. The tendency towards warping on the hot bed is, therefore, quite great, depending upon the proportions of the rail. For rails with a thin web it is customary to use more reduction at the two ends of the web than in the center (in the finishing pass) and to reduce the web less than the foot or the head. The purpose is, evidently, to put the web in tension and thus to counteract (at least partly) the effects of non-uniform contraction on the hot bed.

As mentioned in Vol. I, page 131, it is imnossible to counteract wholly the uneven contraction, which means that the rail will assume a curvature when cold, unless curved in the opposite direction when hot. The latter curvature is put into the rails by a cambering machine consisting of three vertical rolls which virtually are a continuous gagging press. Straightening without cambering rolls can be done by manipulation on the hot bed, but that method requires skill and labor.

Grooved Rails

Grooved rails are used for street railways and were, in former years, rolled in large quantities. On account of the

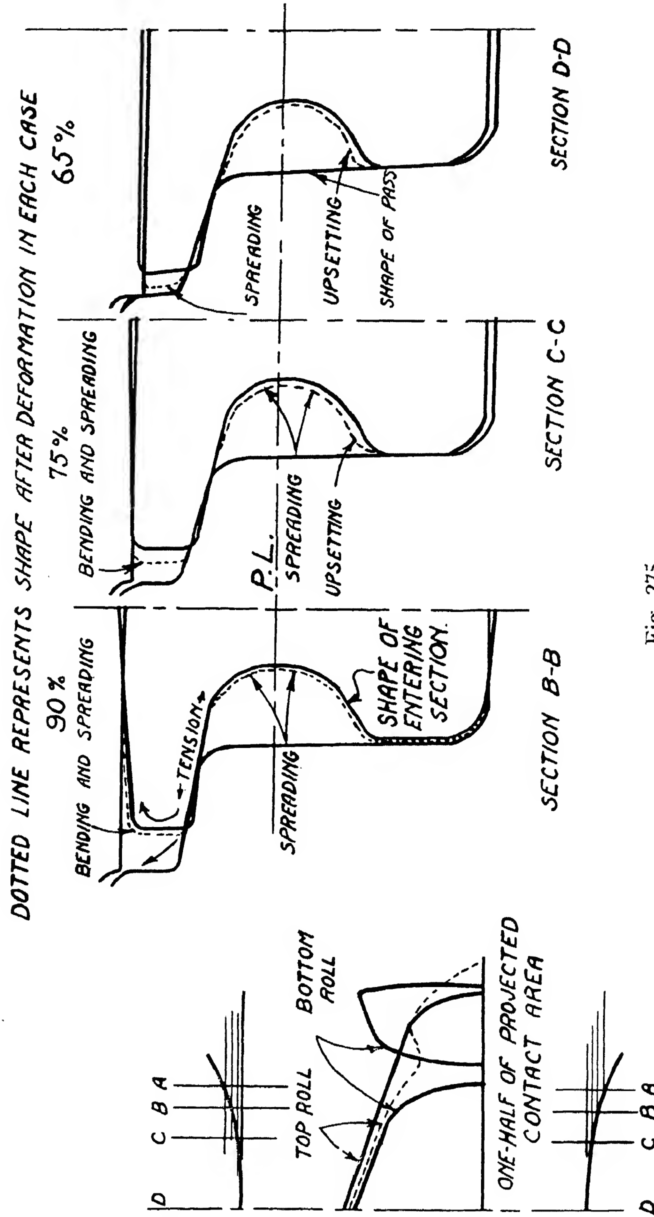

DOTTED LINE REPRESENTS SHAPE AFTER DEFORMATION IN EACH CASE
90 %
BENDING AND SPREADING
TENSION
SPREADING
SHAPE OF ENTERING SECTION
SECTION B-B
75 %
BENDING AND SPREADING
P.L.
SPREADING
UPSETTING
SECTION C-C
65 %
SPREADING
UPSETTING
SHAPE OF PASS
SECTION D-D
C B A
D
TOP ROLL
BOTTOM ROLL
ONE-HALF OF PROJECTED CONTACT AREA
A B C
D

Fig. 275

motor bus replacing the street car, the business is now limited to replacing a limited amount of worn out rails.

However, grooved rails, as rolled in the United States, have two characteristic passes which merit description.

Grooved rails are rolled exactly like ordinary rails by the slab and edging method, as represented by Fig. 271. Usually there are two dummy passes. The difference occurs in the finishing stand which is shown in Fig. 276, together with the

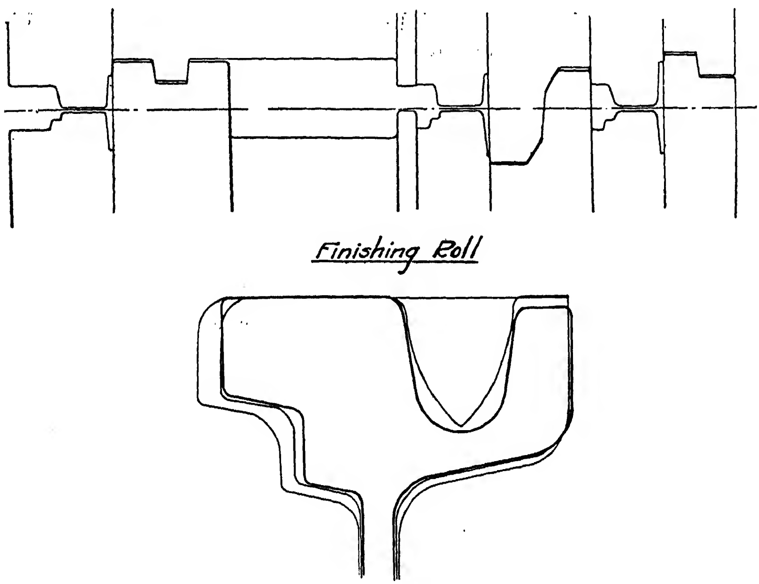


Fig. 276

top of the rail after leaving the leader pass and the finishing pass. These passes are characteristic, because disk shaped rolls with vertical axes are used for rolling the groove into the head of the rail. The disk at the extreme left, between the roll necks (not shown) cuts into the head of the preleader pass, while the disk in the gap near the center of the rolls rounds the groove in the leader.

The disk rolls are a difficult and troublesome piece of machinery. If the bearings are made of sufficient size to prevent excessive wear, the main rolls are weakened too much.

In consequence, a compromise is necessary. Synthetic fiber bearings with water cooling have been successfully used for the journals of the disks.

Cutting into the head of the rail produces quite a reduction of cross section. It is taken care of partly by spreading (filling of corners) but mainly by elongation. This means that, in the preleader pass, the bar and the web must be given enough reduction, to almost equal the reduction given to the head by the formation of the groove. There must also be reduction in the leader pass. The finishing pass has the usual reduction. On account of the groove being in the head, reduction in the finishing pass can be obtained by sidework only (horizontal compression).

Rerolling of Rails

Worn-out rails either are rolled into smaller rails (for industrial railways) or are slit or else go back to the open hearth furnace. The commonly used method of rerolling rails is shown in Figs. 277 and 278. A glance at the illustrations shows that, in these rolls, the diagonal method of rolling is used.

The problem is to reduce various sizes and variously worn rails into good rails of smaller size, in the smallest number of rolls. The roll shown in Fig. 277 is an excellent roughing roll for that purpose. Fig. 278, Plate V, is the finishing roll.

The action of the rolls upon the rail cannot be followed by looking at the passes. To make it clear, Fig. 279, Plate VI, was drawn, which is a section-by-section analysis of a rail being reduced in size. It is quite evident that a buckling or bending action of the web must take place in the pass. The illustration deserves careful study, because it reveals the many force actions and local deformations that go on in one pass.

Irregular and Complicated Shapes

Shapes other than those heretofore described are commonly known as special shapes, although the line between regular shapes and special shapes cannot be sharply drawn. Some of the shapes are so nearly regular that they offer little

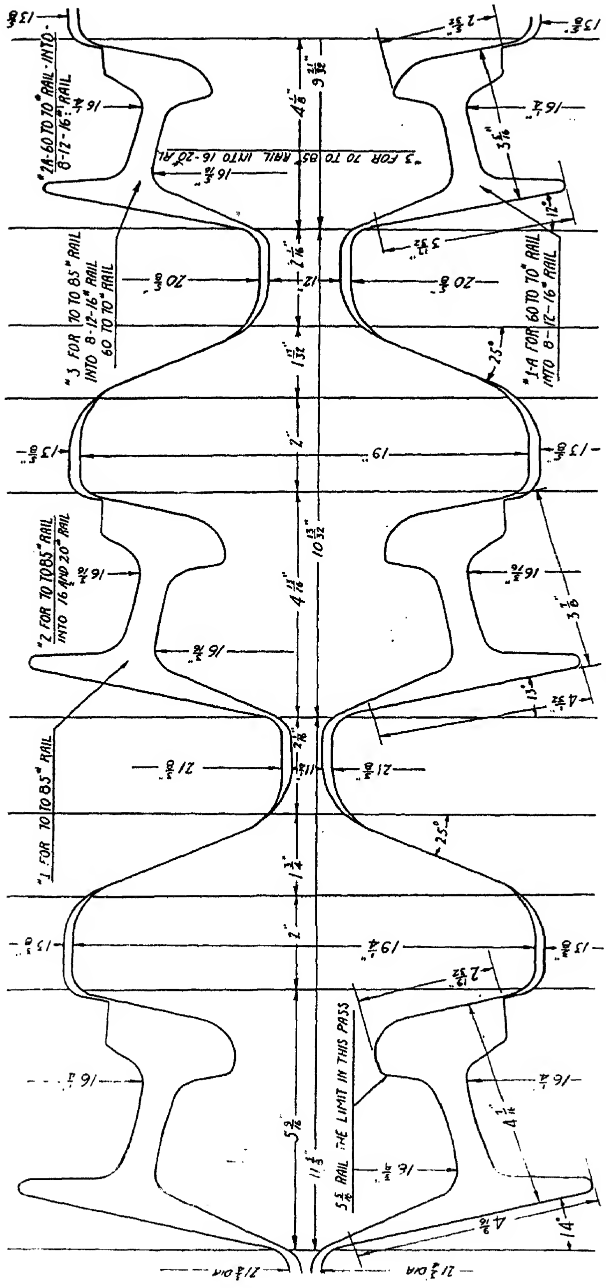


Fig. 277

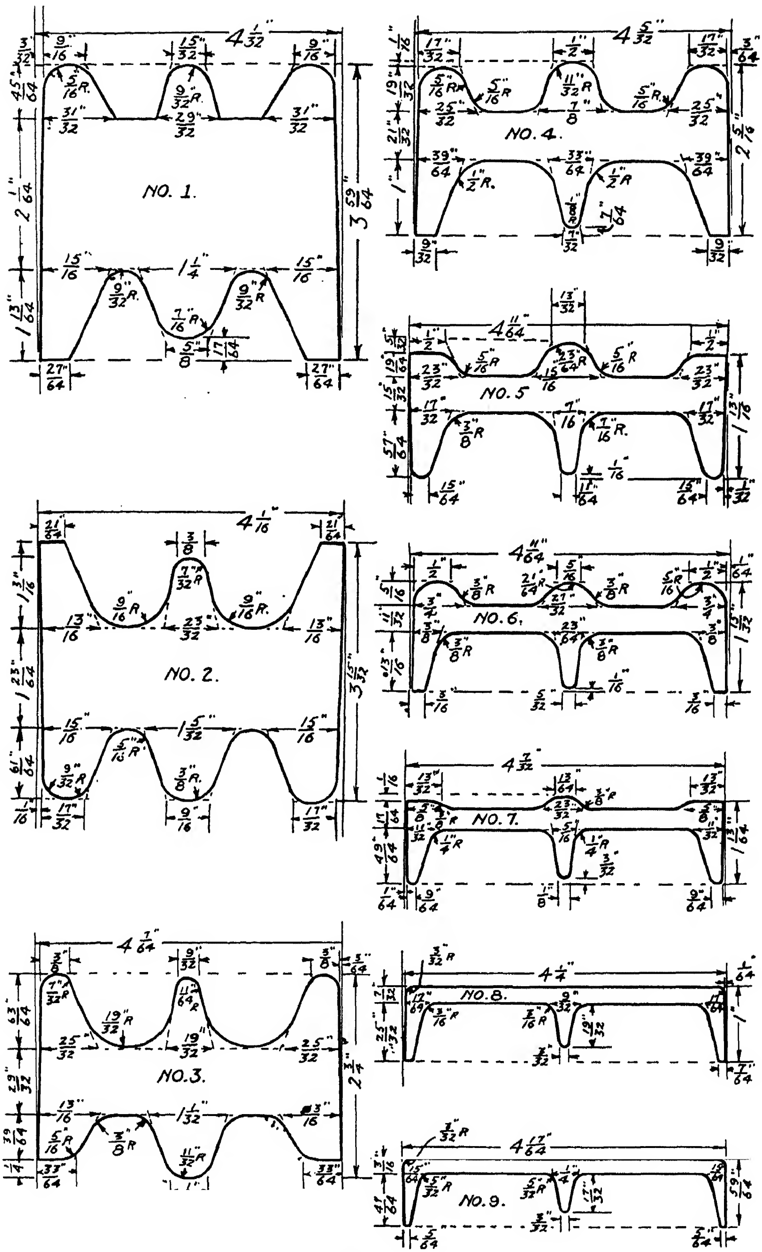


Fig. 280

or no difficulty to the roll designer, while others strain his ingenuity to the utmost.

The principles which underlie the rolling of any of these shapes were explained in Vol. I. At this time, applications are to be discussed with comment upon the methods of rolling.

Most special shapes are small in cross section, and serve for agricultural machinery, window sash, typewriters, automobiles. Nevertheless, larger sections are also encountered, such as tie plates, rail joints, and other railway equipment, and sheet piling (piling beams).

Fig. 280 illustrates a tie plate with one center rib, and Fig. 281 a tie plate with two center ribs. The method of rolling these sections is so much like that of an ordinary channel that very little comment is needed. Attention may, however, be called to the great depth (4 inches) of the entering section shown in Fig. 280, compared to that of the finished section (less than 1 inch). It is clear from these dimensions that a considerable amount of pulling down of the flanges and ribs of the section occurs in these passes. It should be mentioned that the center rib of this section can receive no sidework, slabbing action, or direct compression. The bar is turned completely over (through 180 degrees) between passes 3 and 4. In Fig. 281, the seven passes shown correspond

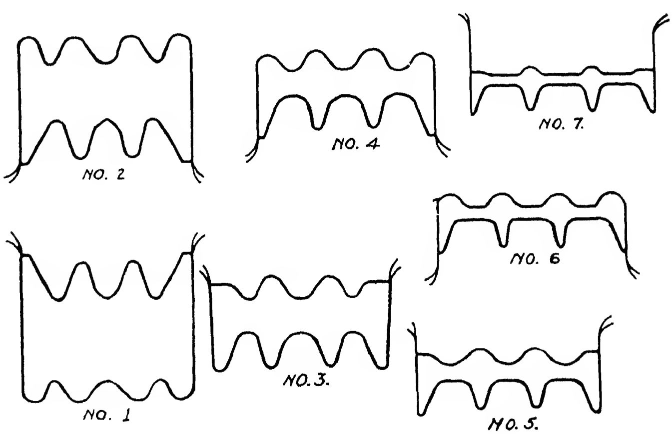


Fig. 281

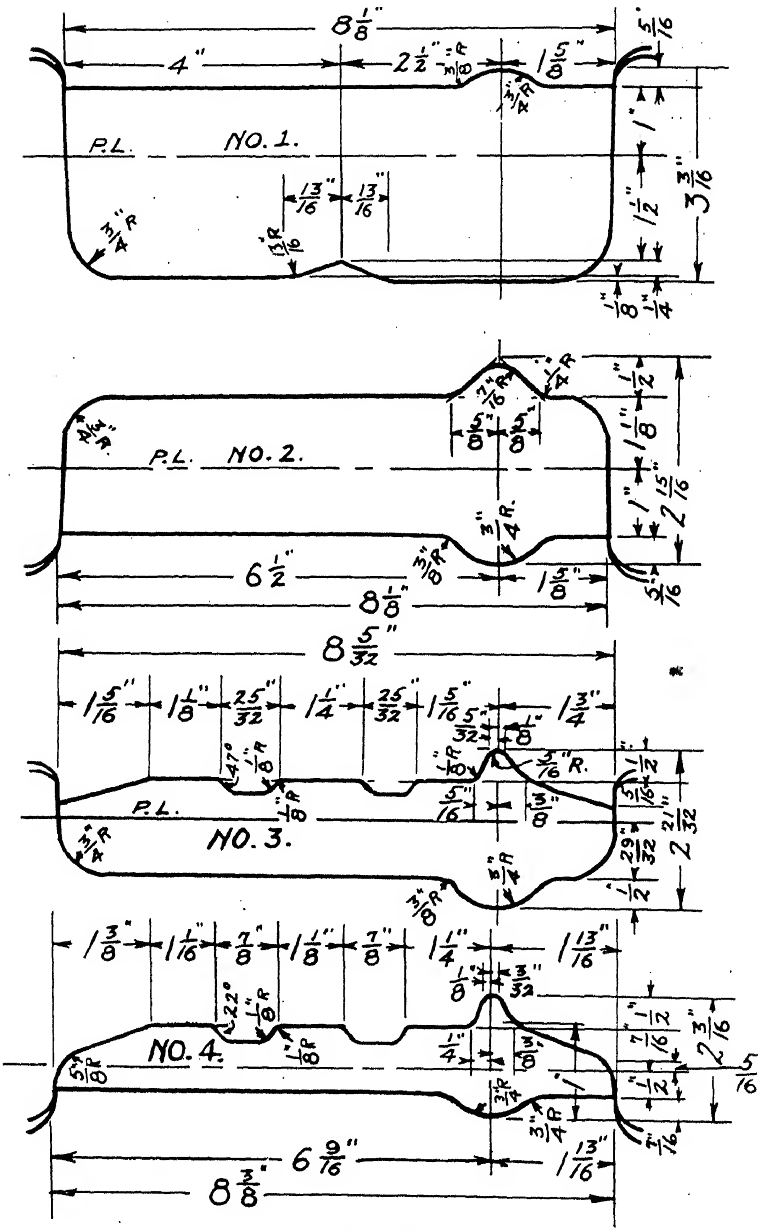


Fig. 282-A

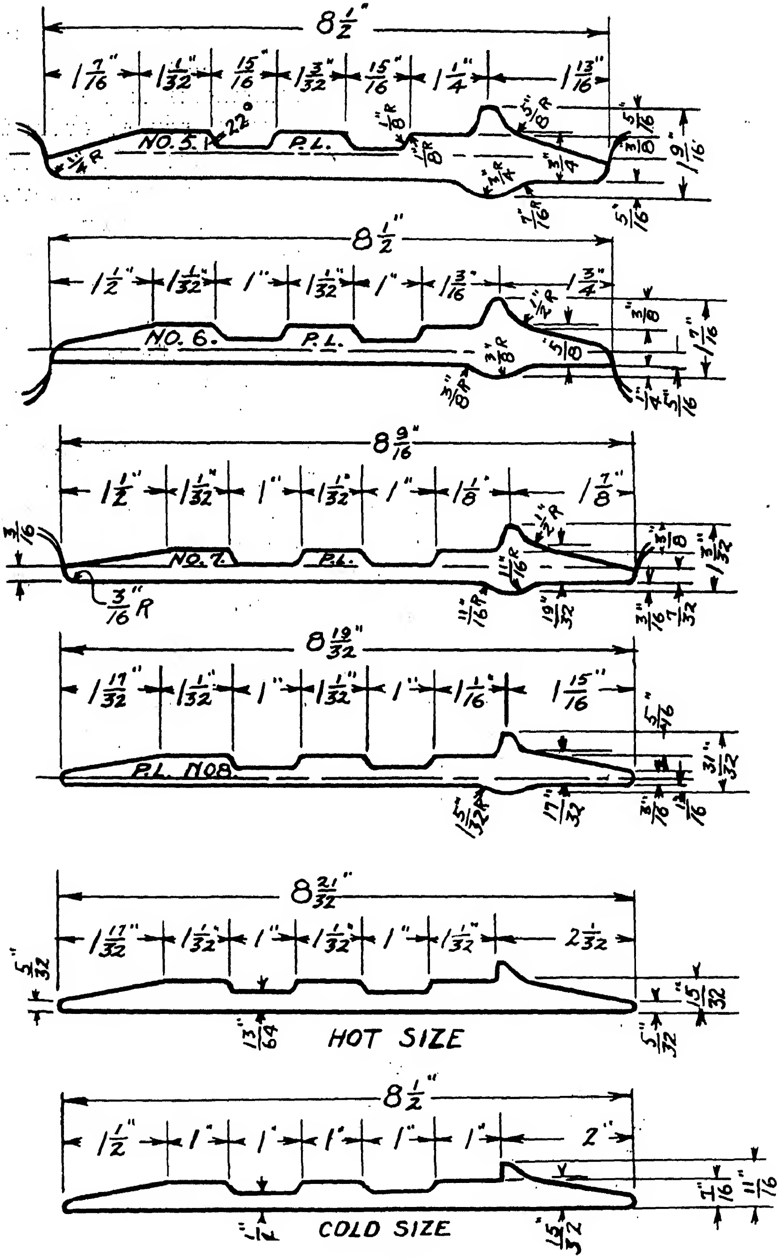


Fig. 282-B

approximately to the first seven passes of the series illustrated by Fig. 280, and are followed, as in the latter series, by a leader and by a finishing pass. Measurements of the passes of Fig. 281 show that the area of the bar is reduced about 20 per cent in each of the first two passes, and about 30 per cent in each of the five following passes, and that the inclination of the inner wall of the flange is practically constant in the last four passes. The statement made above with regard to the center rib of Fig. 280 applies with equal force to the inner ribs of Fig. 281. In other words, they lie always in the dead hole. However, the inside walls of all of the flanges of Fig. 281 have a much greater inclination than those of standard channels. In consequence, heavy reductions are permissible in all passes. Fig. 282 illustrates the rolling of a tie plate of a more modern design. In Fig. 282, the depression in the bottom of pass 1 is probably intended to be used for ragging. It would probably have been equally effective to design the sidewalls of the pass with greater inclination, which would also have made redressing less costly. The tendency to make the uneven reductions in the early passes and to have proportional reductions in the last passes is quite evident in these three illustrations. The use of a "temporary flange", similar to that used in the beam-roughing method of rolling channels, is also illustrated in this series of passes. It will be observed that protection of the edges of the section in these passes, as in most passes for the rolling of special shapes, is accomplished by the suppression of lateral spreading.

Fig. 283, Plate VII, illustrates the passes for a rail joint (splice bar). It must not be imagined that the first few passes are completely filled. In particular, the corner of the upper hump of the first pass might well be rounded more generously. The illustration is somewhat idealized. The passes are shown as if they were all located between two rolls only, while, in reality, they are arranged alternately between bottom and middle rolls and middle and top rolls. The same statement holds true for the second pass of the second roll. The top pass is identical with the bottom pass, but is, of course, reversed; which fact avoids the necessity of turning the bar over. The arrangement of passes in the mill may be taken

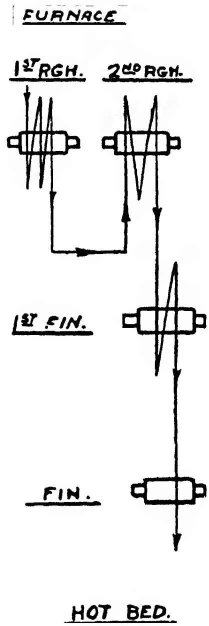


Fig. 284

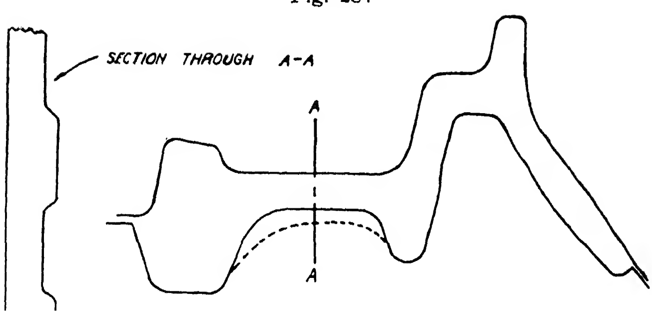


Fig. 285

from Fig. 284. Again, the quick approach to the final form in the first few passes, and the use of proportional reductions near the finishing end are very noticeable. The finishing pass for this rail joint lies in a separate stand of rolls; it is illustrated by Fig. 285. It will be noted by inspection of the left hand portion of the illustration that the cross-section along

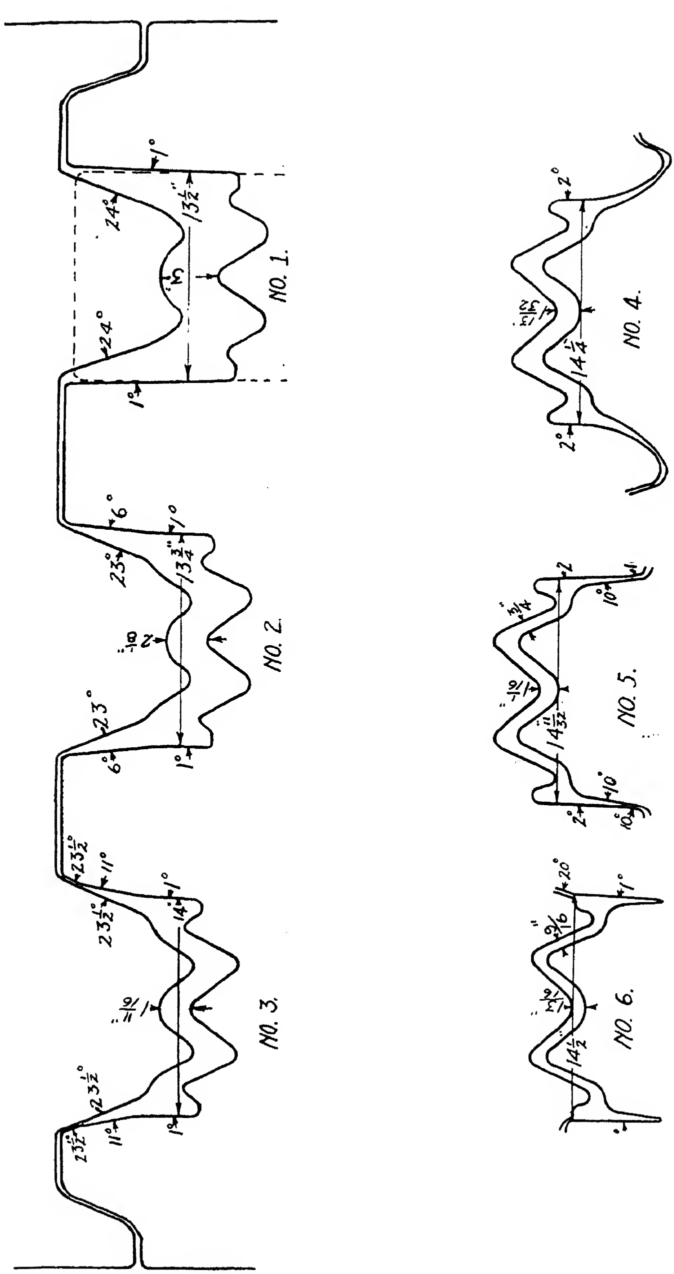
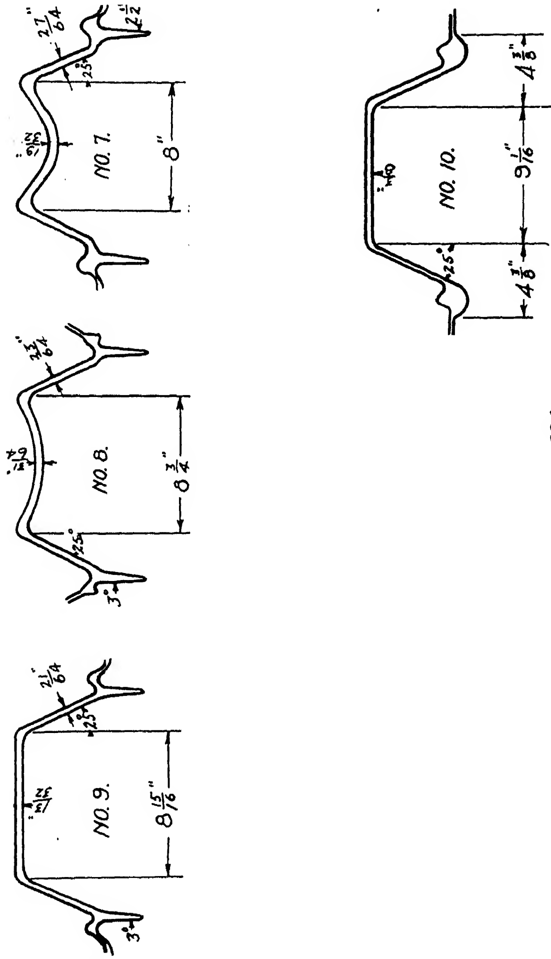


Fig. 286.

the bar is not constant, but variable. On account of that fact, the finishing pass does "periodic rolling" or "deformed rolling" or "die rolling", with very small reduction in spots and great reduction in other parts. In consequence, the finishing pass wears rapidly, which fact accounts for the use of two finishers and two leaders.



286.

An extremely instructive set of passes is offered in Fig. 286, which illustrates the passes for an arch piling section. Notable is the enormously large contact angle, when the bloom

enters the first pass. With the information given (13 inch x 13½ inch bloom, 36½ inches pitch diameter), the biting angle is 47 degrees at the top. If the bloom centers itself at entrance, the angle is reduced a few degrees. In any event, it calls for ragging and for slow biting, and probably also for a good speed of the table rollers. The first three passes lie in a two-high mill. It is questionable whether the bite is slow enough with a steam engine drive. A motor is better.

The flanges in the first three passes do not fill. In a case like the present one, the reductions of the flanges and of the web must be watched. If the reduction of the web is too great (in comparison to the flange), the flanges are crippled. If the reduction of the flange is too great, an overfill may result. The depth of the corrugations in the roughing roll is very pronounced. Their purpose is identical with that of the corrugations in Fig. 262, namely to roll a wide, very thin section from a comparatively small bloom, by pulling the corrugations apart in the leader and finishing pass. After the third pass, the bar is turned over. The edges of the flanges receive no compression (protection) until the sixth pass. Good steel must, therefore, be used.

The forming of the horns in pass No. 7 is of interest. The inclined sections of the web (marked *A* in pass No. 7) pull the corrugations of pass No. 6 apart and push the vertical horns apart, bending them outwardly.

Since the depending flanges lie in the dead hole in passes 6, 7, 8, and 9, they become shorter all the time, which means that in roll design, starting from pass 9, they must be made longer in the order of passes 9, 8, 7, 6, being longest in No. 6.

The bending action in pass No. 10, forming the claw by bending of the depending flange and of the horn is clearly shown.

A set of passes of this sort requires unusual skill in roll design, and is seldom free from surprises in the rolling of the first bar. As a rule, slight changes are necessary, before success is attained.

Tire sections for automobiles and trucks are among the comparatively simple special shapes. Fig. 287 is a series of

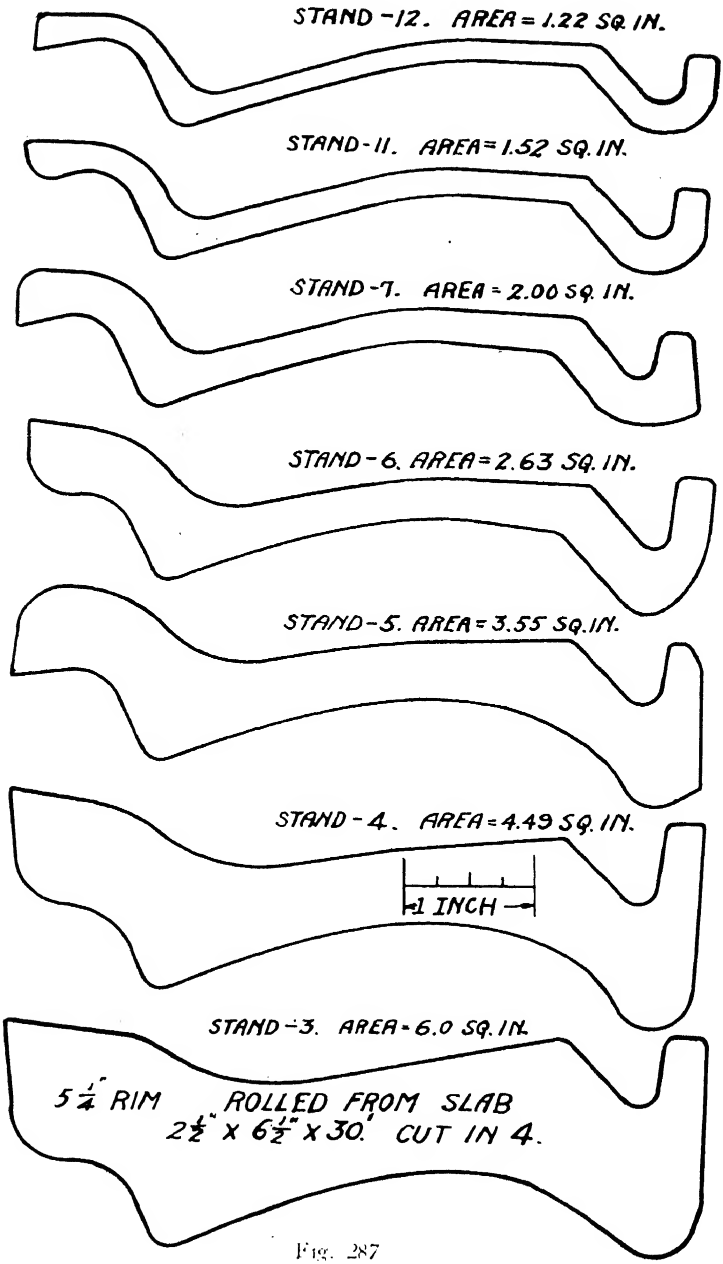

STAND -12. AREA = 1.22 SQ. IN.
STAND-11. AREA = 1.52 SQ. IN.
STAND-7. AREA = 2.00 SQ. IN.
STAND-6. AREA = 2.63 SQ. IN.
STAND-5. AREA = 3.55 SQ. IN.
STAND-4. AREA = 4.49 SQ. IN.
1 INCH
STAND-3. AREA = 6.0 SQ. IN.
5 1/4" RIM
ROLLED FROM SLAB
2 1/2" X 6 1/2" X 30.' CUT IN 4.

Fig. 287

templets for a rim section. Although the rim section has practically uniform thickness, it cannot be bent from a flat strip, because the corners would not be sharp enough. Reductions are nonuniform in the first pass, and rapidly become more uniform towards the finishing pass.

The section presents no novel or intricate features, and is offered here solely for the reason that there is great demand for a section of this type.

Many sections are required by customers to have sharp, right angled corners, either because the bars are to be cold drawn with right angles (in which case departure from the right angle would quickly wear the drawing dies out of true) or else because the bars are to be used without any additional finish, with the possible exception of buffing. For such sections it is advisable that they be finished in a position inclined

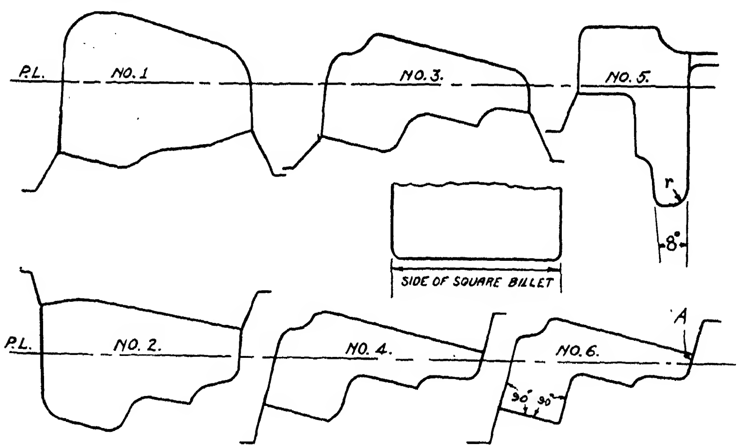


Fig. 288

to the pitch line, for the purpose of securing a well-filled section coupled with easy delivery of the bar from the rolls. The section shown in Fig. 288 (which was adapted from the before-mentioned book by Piron) is a good example for such a requirement.

The radius r at the bottom of the edging pass 5 must be so selected that a reasonably sharp corner is obtained at point A, pass No. 6.

The amount of spreading determines whether an underfill or a fin will be formed at the upper right hand corner of pass 6, and this amount depends upon the material being rolled, the smoothness of the rolls, and the temperature distribution in the bar. The amount of spreading must be determined in each case so as to suit the individual conditions of that case. As previously stated, the careful roll designer will make the radius at the bottom of pass No. 5 too large, and will reduce it if the finishing pass is not properly filled. For safe delivery, the boundaries of the edging (leader) pass No. 5 cannot be parallel and rectangular. The angle of inclination is given in the illustration. It goes without saying that the final distribution of metal is approached as much as possible in the first two

In order to prove the statement that a given section can be rolled in different ways, the rolling of the double angle or "crazy tee" is illustrated by Figs. 289 and 290.

The following features of the passes in Fig. 289 are revealed by a study of the illustration: The first four passes are conventional roughing passes for tees, and pass 5 is the first of the series which departs from convention. In pass 5, the stem lies in a dead hole, and can therefore be reduced only by upsetting. The table, however, is compressed very heavily, particularly on the right hand side, and is also bent by the shape of the pass. The unequal reduction, together with the fact that the stem is too large to be pulled along by the reduction of the table, naturally results in a great deal of spreading. Pass 5 has been so designed that the material of the table cannot spread toward the right. Consequently, the combined bending and spreading toward the left from the flange which is to project upwards from the table, and convert the section into a form which is very similar to the desired final form. Except for the formation of the depression on the under side of the table in pass 6, proportional reductions are used to as great an extent as possible in the remaining passes. The fact that the bar is edged before entering passes 3, 6, 7, and 8, indicates that the designer of these passes did his best to obtain edging passes for the purpose of protecting the edges and obtaining direct slabbing action.

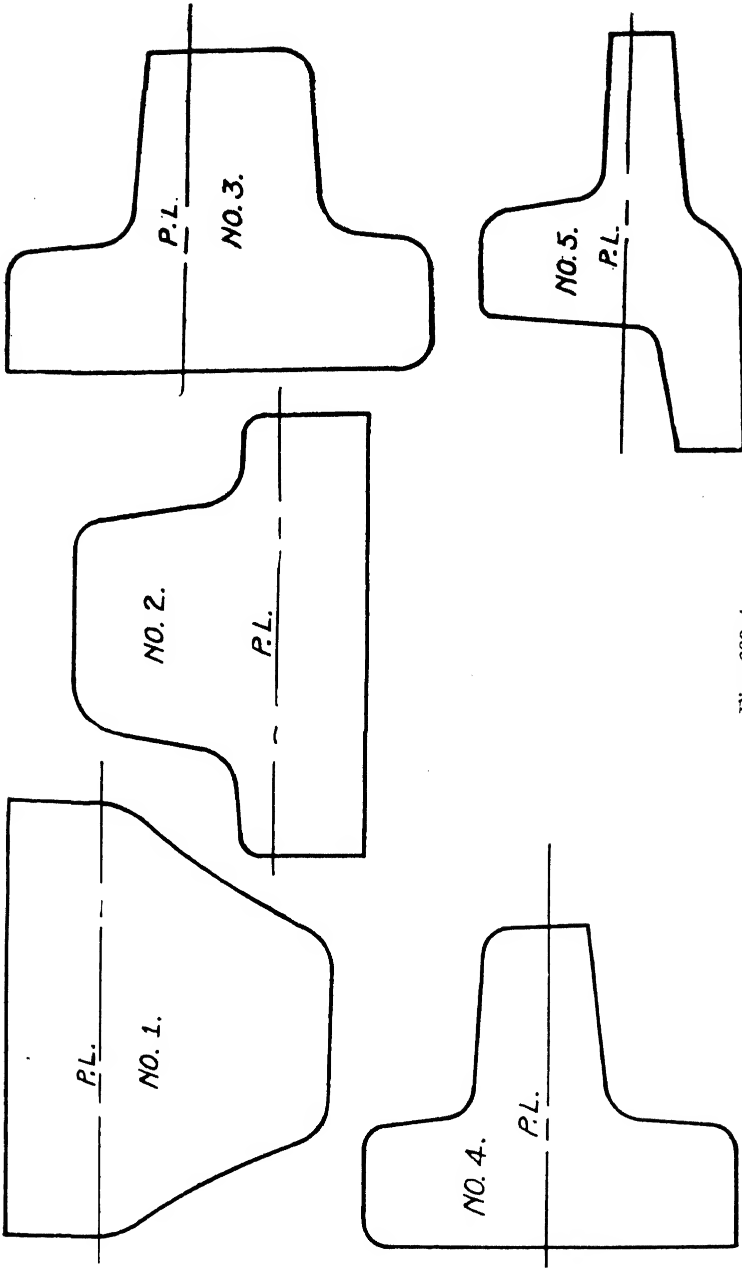


Fig. 289-A

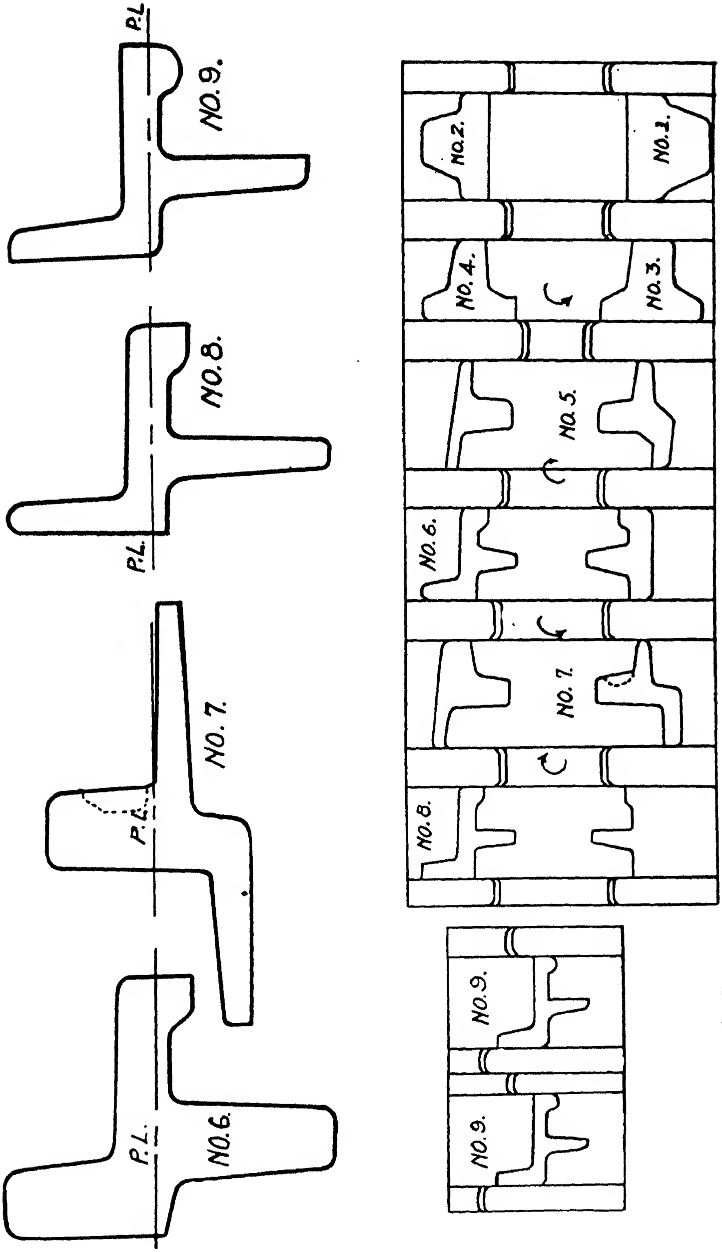


Fig. 289-B

As previously stated, the finished section of Fig. 290 is practical identical with that of Fig. 289, but it is rolled in fewer passes. Several breakdown passes have been omitted, and a diamond pass has been called pass No. 1. It enters into the well known bell pass No. 2 which is so much used in rolling T-sections, and which is probably not filled at the sides.

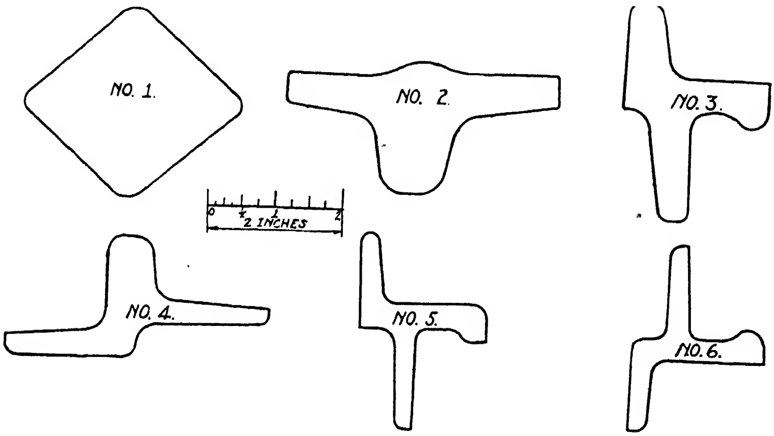


Fig. 290

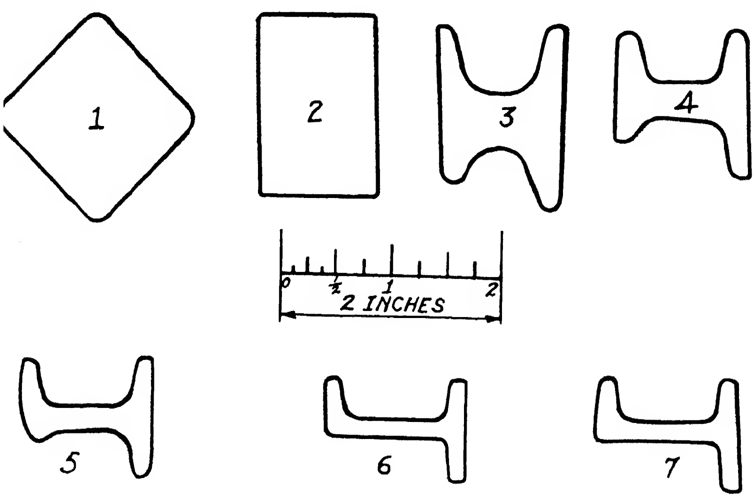


Fig. 291

The truly bold pass is No. 2 into No. 3. The bar can enter in an inclined position only, and very careful guide setting is required. From No. 3 on, the rest is easy.

As an example for the rolling of a strongly unsymmetrical section Fig. 291 is offered, which was made from the templets. Preparatory passes needed to arrive at the correct size of square were omitted.

These passes show that templets must be studied critically. If the rectangle, pass 2 is to be rolled from the square pass 1, on the flat, the spreading would not be sufficient to fill the rectangle, unless very large and rough rolls were used. The square would not enter on the diagonal, but the rectangle may lie diagonally in the rolls, in which case the square can enter diagonally and will almost fill. Even if it does fill, pass No. 3 would not fill, because the entering wedge is too blunt. From pass 4 on, the section fills much better. Again, the quick approach to the final section in the early passes, and the use of proportional reductions toward the finishing passes is quite evident.

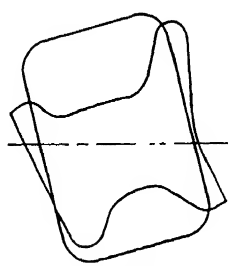


Fig. 292

The passes in Fig. 291 have doubtless been used, but they can be improved upon, by entering the rectangle inclined, as indicated in Fig. 292 and then rolling on the diagonal, inclining the pass alternately right and left, and finally bending the left hand flange into correct position. This requires seven passes.

CHAPTER V

DIE ROLLING

Deformed Rolling, Periodic Rolling, Geared Rolling

As soon as the shape of at least one of the grooves (or sides) of a pass changes along the circumference of the roll, we speak of the process as die rolling, which term originated from the practice of inserting a die (with the special shape) into the roll. The term "deformed rolling" indicates that the shape of the cross section of the bar is not constant, while the term "periodic rolling" indicates that the shape of the bar varies recurrently or periodically. The term "geared rolling" means that top and bottom roll must turn together and pass through equal angles at all times, so that the two profiles or matrices match properly. As a rule, a micrometer adjustment must be provided for the purpose of adjusting the relative rotational positions of the top and bottom rolls.

A very common, but mild, form of die rolling is the branding of structural shapes, rails, etc. The rolling of floorplates and of concrete bars is die rolling, and so is the rolling of ornamental iron work. In practically all of these cases, there is no necessity for maintaining an exact length between the corresponding or recurrent points of two successive revolutions of the rolls.

Certain difficulties arise if periodic sections with widely differing cross sections (in the same piece) are to be rolled and if exact "center to center" distance must be maintained. This feature forms the most interesting part of die rolling.

All die rolling is limited to one pass, viz., the finishing pass, because it is impossible so to enter a previously die-rolled bar that it matches the depression in the rolls. An exception is formed by the so-called "gap mills", in which the

forming part extends over about 50 per cent of the circumference, while the rest of the roll circumference is idle, and is reduced in diameter. The blank to be rolled is fed into the forming part and is drawn back again from the idle part. Rolling in the gap mill is not continuous, but is a step by step swaging action. On account of the intermittent action, the speed of a gap mill must necessarily be low.

Forward slip, or the extrusion effect, is of importance in all die rolling. If, for instance, the letters for branding are too deep (that is to say, if the reduction in the finishing pass is too great) the letters are wiped over and become indistinct, because they are held by the rolls while the bar slips forward. In consequence, the letters are made, as a rule, only 1/32-inch high. They could be higher if the finished section were thicker, because it is the relative and not the absolute reduction that counts.

For this reason, the projections of floorplates, of concrete bars, or waffling of tieplates can be deeper than the branding on the thin web of structural material. Furthermore, forward slip is very much affected by the temperature of the bar and becomes almost zero if the bar is very hot. Since thick sections finish hotter, they can be provided with a deeper pattern. If the section is thick and hot, the pattern may easily be ¼-inch deep, particularly if the contour of the pattern is rounded.

Letters for branding are almost always made with amply rounded edges. Letters which are sharply outlined in the roll usually produce very indistinct brands, even though the letters may be very shallow.

Die rolling with considerable difference of cross section in the same bar brings with it the following difficulties:

If the pass is open, the strongly reduced sections either produce a fin, or if the fin is avoided the slightly reduced or only deformed sections produce an underfill. Rolling with a fin is indeed done, in which case the fin or "flash" is later trimmed off. Since this trimming means an extra operation, die rolled parts were, for many years, so designed that the whole deformed bar could be rolled from a given leader without overfill. Fig. 293 illustrates the meaning of this statement.

The oval leader is deformed into a round section and into a flat, which forms a silo strap or gasoline tank strap, with round ends for bolts. The same leader serves for both. Another very characteristic bar was the wagon spoke which was round at

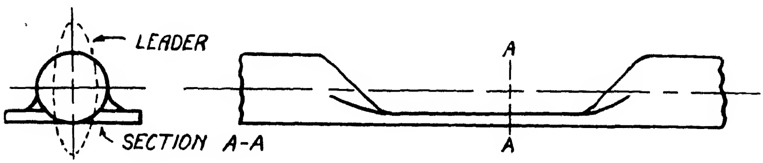


Fig. 293

one end, and oval at the other, as shown in Fig. 294. The leader is a very flat oval, which makes both the oval at one end and the round at the other end, as well as the intermediate sections.

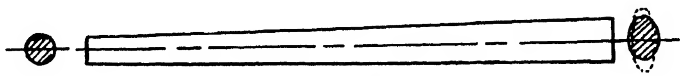


Fig. 294

Much ingenuity was spent in conferences between customers and roll designers in order to produce bars that could be rolled in open passes without fins. If that was not possible,

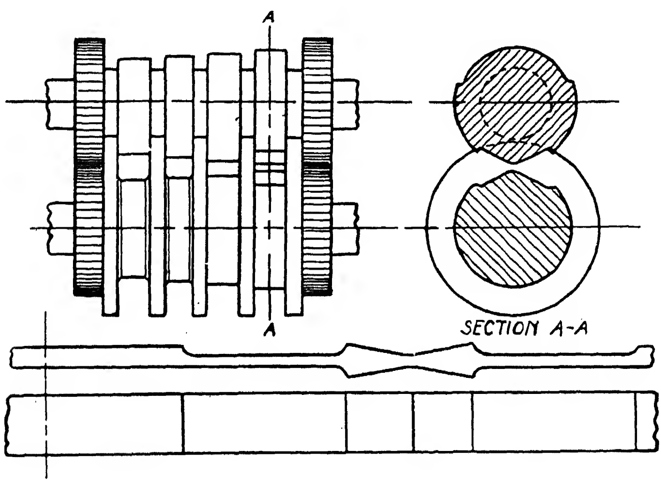


Fig. 295

closed passes were often employed, for instance in the rolling of horse shoe blanks, or of tieplates. Fig. 295 illustrates this method of tongue and groove rolling. If the tongue and groove are deep and fit closely enough, no fin is formed. Evidently this method is limited to rectangular or nearly rectangular sections.

One of the best examples for bars that cannot be die rolled without a fin is a circular bar with varying diameter. Such a bar is diagrammatically shown in Fig. 296. The leader is so proportioned that it just fills the largest diameter, and produces a fin or overfill, or rib, for all other sections. The greater the ratio of diameters, the wider the fin, the greater the shear

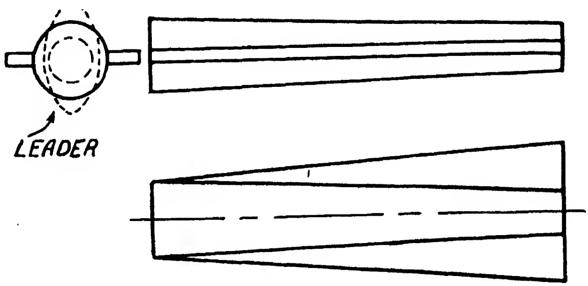


Fig. 296

loss, the greater the roll spring, and the wear of the rolls. Reductions of 80 per cent (neglecting the fin) in one pass (the finishing pass) are on record with a roll-pass life never exceeding six hours. The trimming reduces the yield and calls for location of the mill near an open hearth plant.

In connection with maintaining the exact length of the periodic bar, several important problems arise. The effective radius, active radius, ideal radius (see Vol. I, page 121) is of paramount importance in die rolling. It varies in magnitude with the reduction, the temperature of the bar, the temperature of the roll, the smoothness of the roll, and with the shape of the projected contact area. If the bar is rolled with a fin, the projected contact area of that fin must be taken into account. Since the fin is usually formed rather late in the pass (that is to say, near the line of roll centers) the grip of the rolls is hardest near that place and forward slip is small.

For obtaining correct center-to-center distance of corresponding points in the bar, the roller has the choice of several adjustments.

1. Increasing the size of the leader increases reduction and forward slip. The bar is lengthened.

2. Reduction of temperature of the entering bar increases forward slip and thereby lengthens the bar. The expedient of reducing the temperature of bar must be used for small adjustments only, because the resistance of steel to compression grows enormously as the temperature falls; steel of low temperature wears the pass very quickly. In mill parlance, "Cold steel burns out the pass". (In passes with a wide fin, this adjustment has little effect, see preceding page.)

3. Variation of rolling speed. At low velocities, speeding up lengthens the bar, the same as it does in ordinary parallel rolling (see Vol. I, page 92). At high velocities speeding up shortens the bar, because the rolls skid on the steel during those periods when the bar is accelerated into the rolls, the acceleration being due to change of cross section. This method of length control is very unreliable and uncertain; it should be avoided.

4. Variation of quantity of water on the rolls. Dry rolls cause very short bars, because the rolls skid on the steel. This method of length control is dangerous, because dry rolls wear smooth (but *do* wear) and crack later on.

All of these adjustments work within very narrow limits only, particularly if the bar is rolled with a wide fin. The comparatively small effect of the adjustments can be judged from Fig. 297 and Table XXV, which contain information on the rolling of tapered bars of circular cross section.

TABLE XXV (refers to Fig. 297)

Average temperature, degrees, F.	Speed, r.p.m.	Average length, inches A	B	C	D
1773	53	2-1/4	7-3/32	17-27/32	4-7/8
1483	51	2-9/32	7-1/8	17-7/8	4-27/32
1481	37	2-9/32	7-1/8	17-7/8	4-7/8

In the rolling of this bar, the forward slip (based upon

the outer edge or perimeter of the rolls) is 7.52 per cent at 1773 degrees, and 7.50 at 1483 degrees Fahr. It might be expected from information given in Vol. I, page 118, that the forward slip should be much greater at the low temperature. With bars which are rolled without a flash or fin, that expectation is fulfilled, but in the present case the wide fin overpowers by its action the whole rest of the bar. The fin is the hottest part of the bar, due to the great compression work which is receives. If the bar enters at low temperature, the fin

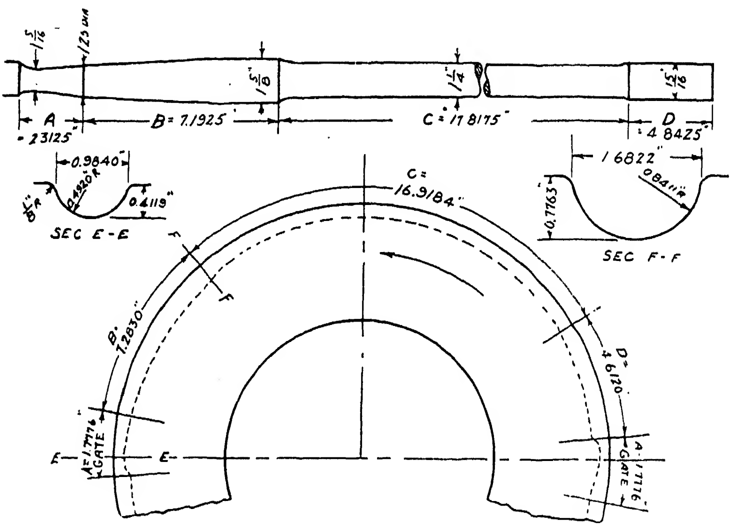


Fig. 297

offers more resistance, and more work is converted into heat, with the result that the fin has practically the same temperature in either case. The difference between 7.52 per cent and 7.50 per cent can easily be due to errors in measurement.

In laying out matrices for die rolling several precautions must be observed, the principal ones of which follow:

I. On account of the very rapid wear of the die rolls, frequent redressing is necessary. Each redressing shortens the circumference of the roll, and also the distance between corresponding or recurrent points of the bar. The periodic bar becomes shorter after each redressing. For some articles, such

as concrete bars or floorplates, the shortening is of no consequence; for others it is important, and for still others it cannot be permitted. To the former class belong railroad tieplates, Fig. 298, and wire clamps, Fig. 299. Certain railroad tieplates have a slight belly, as indicated in Fig. 298 (which shows only the important feature). After each redressing of the roll, the tieplate becomes shorter. Since there is no objection to fur-

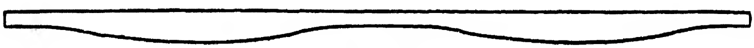


Fig. 298

nishing them somewhat longer than required, they are made too long when the roll is new, and are made within the tolerances for short length when the roll is scrapped.

The same reasoning applies to the wire clamp, Fig. 299, with the additional condition that it will not do to put a very short top clamp on a very long bottom clamp. In this case,

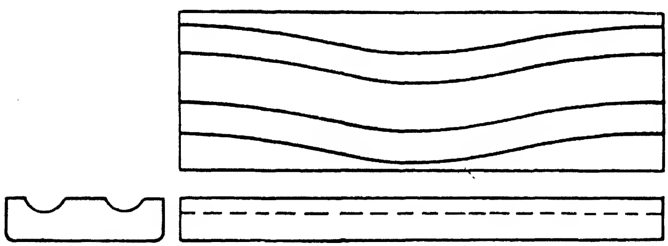


Fig. 299

change of leader size and change of temperature are used to help out.

For complicated profiles with rigid requirements as to length, waste metal (called "the gate") is allowed between successive blanks. Each redressing encroaches upon the length of the gate; the rolls are scrapped when the gate has been used up. Use of this method presupposes that the profile permits lengthening. A profile which does not permit lengthening is shown in Fig. 300. The contour after redressing is shown in dotted lines. Evidently the shaded portions would have to be filled in, and the hard roll material does not permit filling in.

II. In laying out a matrix containing small (shallow) and large (deep) cavities, the length "a" (see Fig. 301) of the small cavity is purposely made slightly too great. After a few trial bars have been rolled, the length corresponding to "a" on the finished bar is measured. If any corrections are neces-

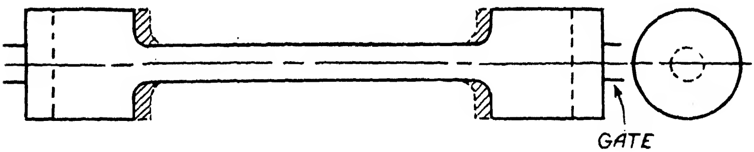


Fig. 300

sary, they can readily be made by reducing the length, "a", whereas the opposite process is out of the question.

III. In the rolling of taper parts, the position of the neutral point differs from that which it has for parallel rolling.

To explain this statement, Figs. 302 and 303 were drawn. The difference between parallel rolling, "rolling on" and

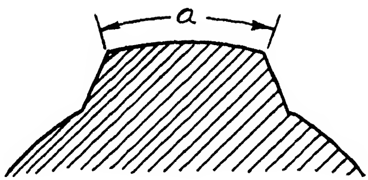


Fig. 301

"rolling off" is shown by Table XXVI, in which the values represent lengths in the direction of rolling.

TABLE XXVI

Parallel		Rolling on		Rolling off	
Matrix	Product	Matrix	Product	Matrix	Product
4.6120	4.844	7.283	7.130	16.918	17.855
5.03 per cent lengthening		2.11 per cent shortening		5.69 per cent lengthening	

These data refer to Fig. 297. The "parallel" division corresponds to section *D* of the bar shown in Fig. 297, the "rolling

on" division corresponds to section *B*, and the "rolling off" division corresponds to section *C*.

Strictly speaking, the hot lengths of the product should have been compared to the warm lengths of the matrix, but

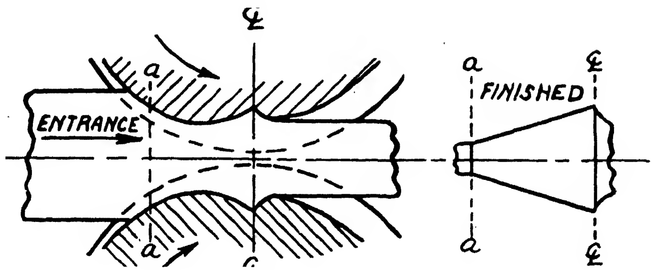


Fig. 302—Rolling off

the cold lengths were more easily measured. Since the shrinkage in cooling is about 1.7 per cent, the actual shortening in "rolling on" is only 0.4 per cent, which is negligible, but the difference in effect between rolling on and rolling off is very marked.

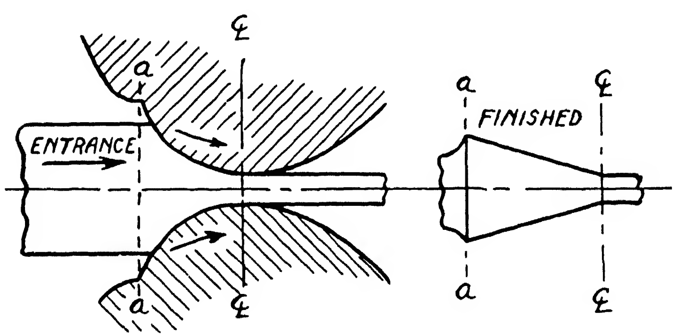


Fig. 303—Rolling on

Roll designers must take care of this difference, and must lay out the matrix for a new profile in such a manner that metal can be dug out of the groove after the rolling of a few trial bars, for the purpose of producing correct lengths later on. A certain amount of cutting and trying cannot be dispensed with.

IV. Roll spring varies suddenly (within one revolution of the roll), on account of variation of reduction and variation of projected contact area. Roll spring must be allowed for in the depth of the groove, as shown in Fig. 297 by the dimensions of sections EE and FF. It is approximately calculated by the methods explained on pages 42-48 of Vol. I; on the basis of these calculations the groove is made slightly too shallow and is then brought to correct dimensions after a few trial bars have been rolled.

In order to make die-rolling profitable, there must be a very large market for the product; otherwise, drop forging is more economical.

CHAPTER VI

ROLLING MILL TORQUE

Power Requirements of Rolling Mills

Roll train resistance, by which is meant the resistance offered by the mill to torsion, is of importance in determining the torsional strength of rolls, wobblers, couplings, spindles, gear drives, and in determining the capacity of the driving engine or motor which is required for rolling a given section on a given mill. When a new, rather large section is to be rolled, the roll designer is faced with the problem of investigating the strength of the above mentioned transmission parts and of deciding whether the engine or motor which drives a given mill can supply enough power to roll the new section on that mill. When this problem arises, it is presumed that the strength of the rolls against bending has already been investigated.

For existing mills, the following procedure is recommended: A section, similar to the proposed, doubtful one, but well within the capacity of the mill is rolled. If the mill is engine driven, indicator cards are taken. If the mill is motor driven, wattmeter readings are taken. By making due allowances for the mechanical efficiency of the engine or for the efficiency of the motor, engineers can compute the torque (or twisting moment) delivered by the engine or motor, because:

$$\text{Torque (foot pounds)} = \frac{33{,}000 \times \text{Horsepower}}{6.28 \times \text{Revolutions/Minute}} = \frac{5255 \times \text{Horsepower}}{\text{Revolutions/Minute}}$$

$$= \frac{44{,}236 \times \text{Kilowatts}}{6.28 \times \text{Revolutions/Minute}} = \frac{7043 \times \text{Kilowatts}}{\text{Revolutions/Minute}}$$

$$\text{also Torque (inch pounds)} = \frac{63{,}060 \times \text{Horsepower}}{\text{Revolutions/Minute}} = \frac{84{,}516 \times \text{Kilowatts}}{\text{Revolutions/Minute}}$$

If only the power of the engine or motor is questioned, the torque need not necessarily be computed, because we can judge directly whether the driving unit has enough power for the larger section, by a method indicated below.

If the torsional strength of rolls, gears, shafts, spindles, couplings, or wobblers is in question, the torque must be computed for rolling the trial section as above indicated, and must be recomputed for rolling the new section, as explained in the next few paragraphs.

From Vol. I, pages 10-17, it is known that the resultant force in single stand mills acts at right angles to the direction of rolling, and also that the resultant force depends upon the projected contact area, the material of the bar, its temperature, the friction between bar and rolls, and the compression rate.

Before this force P can be used for computation of the resisting torque, its lever arm r, must be known. The theoretical determination of r (Fig. 304) meets with difficulties, and so does its experimental determination.

For the practical roll designer, the following reasoning, which is based upon similitude of machinery, offers a way out. Similar sections have similar projected contact areas, and it stands to reason that the ratio of lever arm r to distance a (Fig. 304) from center line to "mass-center" of projected contact area will be the same for similar sections. Hence, if the new section has n times the linear dimensions of the old one, the new projected contact area will be n^2 times the old one, and the new lever arm will be n times the old one. On the basis that the unit pressure for similar sections will be the same, we find that the torque (which equals pressure times projected contact area times lever arm) is proportional to n^3. This means that the torque for a section which is 1.2 times as large as the old section, will be $1.2 \times 1.2 \times 1.2 = 1.73$ times as great, if we use the same percentage of reduction.

This method is based on the assumption that other conditions (such as composition of material of bar, temperature, lubrication) are to be the same for the old section and for the new section. If they are not, the result of the test must be modified, by using the information contained in Vol. I.

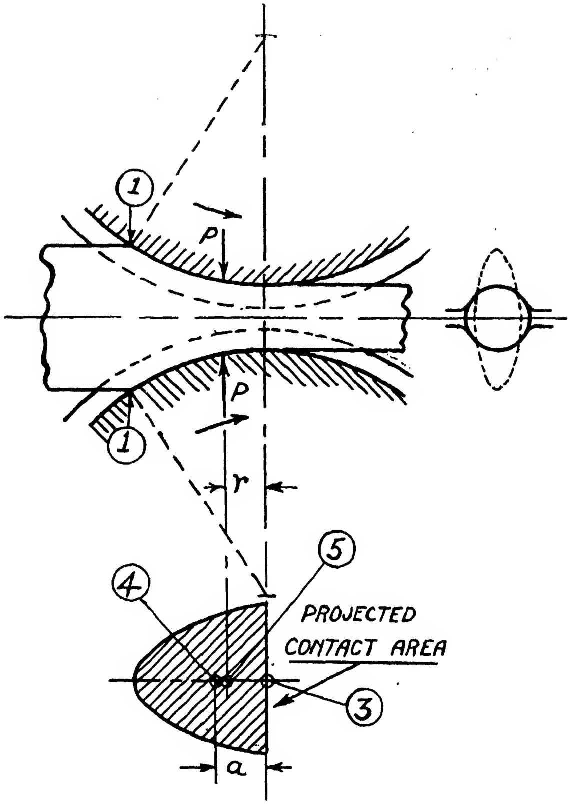


Fig. 304

After the new torque has been computed, investigation of the strength of the power transmitting parts, with the exception of wobblers or specially designed couplings, follows the routine methods of applied mechanics. Calculation of the strength of specially designed couplings is not accomplished by routine methods. When such calculation is necessary it should be done by the engineering department rather than by the roll designer. The strength of wobblers and wobble necks (Fig. 305) is quite difficult to calculate accurately, and in this case an approximation is considered satisfactory. The irregular, or notched, outline is considered as though it were a circle having the same area as shown in Fig. 305. On the basis of this assumption, the strength can be calculated from familiar formulas.

If it is out of the question to roll a similar section, or to go back to records of similar sections, a more general method must be followed, and the following reasoning is useful: Since the separating force is one of the factors of torque (which latter equals force × lever arm), it must be determined. But separating force equals projected contact area times average pressure. The projected contact area is found by construction, as explained

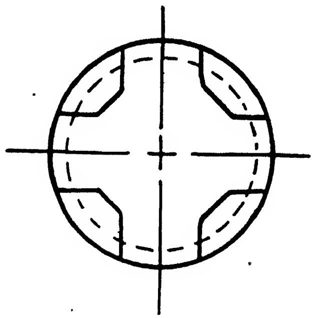


Fig. 305

on pages 102-104 of Vol. I. The average pressure (if steel is rolled) can be taken from the charts on pages 13 and 15 of Vol. I. For some of the other metals, data are given in the Appendix. In the selection of the average pressure, temperature and composition of the bar are not the only variables of importance; the increase of pressure due to friction between bar and rolls must also be considered. On pages 84-86 of Vol. I, proof is given that friction increases the force required for rolling. Collar friction, flange friction, length of contact increase the pressure.

Although the average pressure may be arrived at with a fair degree of accuracy, it is not definitely known, how the pressure is distributed over the projected contact area. If the pressure between rolls and bar were uniform, the resultant force would necessarily pass through the "center of gravity" or "mass center" of the projected contact area. But many forces are at work that shift the resultant away from that point. Some forces increase the acting lever of the resultant, while others decrease it. The forces are:

1. Friction (a) between cylindrical roll and bar.
   (b) collar friction.
   (c) effect of varying friction.
2. Change of resistance due to varying compression rate.
3. Change of resistance due to varying temperature of bar.
4. Adhesion between bar and rolls.

For cold rolling, two important force effects are caused by

5. Flow hardening of bar material.
6. Deformation of roll.

Friction between a cylindrical roll and the flat bar, strip, or sheet not only increases pressure, but also moves the resultant somewhat closer to the line between roll centers than the position it would occupy if no friction existed. In other words: Friction increases the force, but reduces its lever arm slightly (as compared to no friction). The reason for this action can be understood from a study of pages 84 to 86 of Vol. I.

Collar friction, taken by itself, produces a couple which increases the lever arm of the separating force, for this reason: Near the outer edge of the collar the rolls travel faster than the

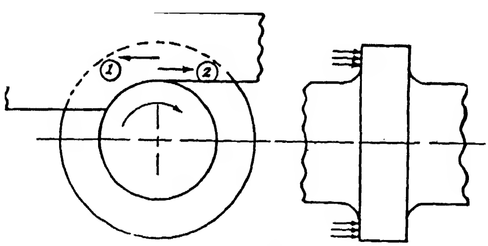


Fig. 306

bar, which means that the bar holds the roll back. Near the root of the collar, the bar travels faster than the roll and pulls the roll along. The two forces are indicated by arrows (1) (2) in Fig. 306. It is readily observed that the couple (1) (2) acts opposite to the rotation of the rolls. Since it does not increase the separating force, the lever arm of that force must be increased.

If both collar friction and cylindrical friction act simultane-

ously, or if the pass has inclined sides, the analysis becomes more complicated.

In hot rolling, the coefficient of friction varies. Water on the rolls flashes into steam between roll and bar, and acts as a lubricant. The steam escapes in all directions, if it can. With slow rolling, and a long contact, it escapes laterally, leaving the last part of the contact without lubrication. This action reduces the lever arm (as will become clear from a continuation of the reasoning on pages 85, 86, Vol. I).

Friction effects are of comparatively small importance for very thick sections, and grow in importance as the section becomes thinner and thinner in comparison to the roll diameter.

Variation of compression rate increases the lever arm, because at entrance compression is more rapid than at delivery. However, the effect is usually small and is overshadowed by other effects.

Change of temperature of bar has a very variable effect, depending upon thickness of bar and speed of rolling. With thin bars and slow speed, the temperature of the bar drops, the material of the bar hardens, and the lever arm becomes smaller. With fast rolling, and especially with thick bars, the temperature of the bar rises, the latter becomes softer, and the lever arm becomes greater than the lever arm of a resultant passing through the mass center of the projected contact area.

Adhesion of the bar (occurring in the rolling of some alloys) increases the lever arm, at the same time reducing the pressure. For that reason, its effect is seldom of consequence for the power requirement.

In cold rolling, flow hardening reduces the lever arm, and so does the elastic deformation (flattening) of the rolls, because it causes contact to extend beyond the center line (between roll centers).

The effect of all these variables is that the lever arm of the resultant is frequently as much as 10 per cent greater than the radius to the mass center, and is also frequently as much as 10 per cent smaller than that radius. Deviations greater than 10 per cent are rather rare and occur only under unusual condi-

tions. The upshot is that great care must be exercised in estimating the lever arm of the resultant force and that all possible influences must be taken into consideration.

The problem really requires more information than is at the disposal of the average roll designer. More than that, it requires information which few engineers possess. Its solution calls for the combined efforts of a committee of mill men and engineers.

But even if the lever arm and the resisting forces have been determined correctly, a great uncertainty arises in determining the correct value of roll neck friction, at least in the commonly used sliding bearing. In ordinary operation of the mill, the coefficient of friction (ratio of tangential to normal force) in the

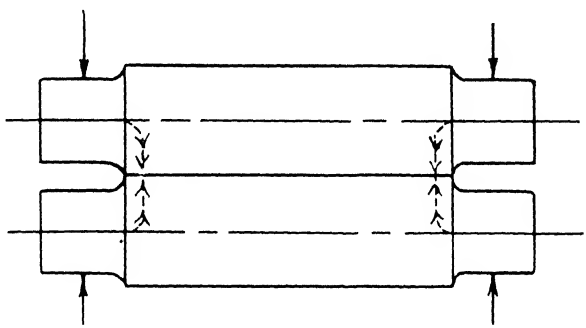


Fig. 307

roll necks cannot be determined. It has been attempted to measure the friction of roll necks by pressing the rolls against each other with a known force and by measuring the friction work. The results of such tests have been misleading, because the forces take the short circuit through the ends of the rolls (see Fig. 307), whereas, in actual rolling the rolls deflect as shown in an exaggerated manner in Fig. 308. The difference between the two roll shapes is vital. In Fig. 307 the roll necks rest in their bearings over their whole lengths, whereas in Fig. 308 they ride on the corners, as shown in the right hand bottom corner. (So-called self-adjusting bearings are usually not self-adjusting). The oil is then squeezed out from the corner of the bearing near the roll, and solid friction, having a coefficient of

30 per cent or even higher, occurs; whereas with the arrangement of Fig. 307, the coefficient of friction may be as low as 3 per cent and probably has an average value of 7 per cent.

The condition shown in Fig. 308 can be approximated by rolling a cold hard bar through the mill, without reduction, in such a manner that the roll and housing spring produce a known, measured force. Such a test is possible only if instruments are available for measuring the separating force.

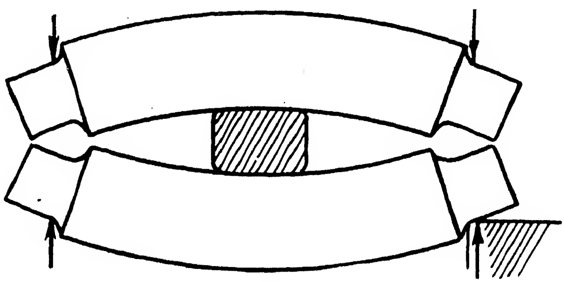


Fig. 308

After the coefficient of friction of the roll necks or the *friction torque* (*of the roll necks*) has been determined, the latter must be added to the above computed torque which is necessary to compress the bar (and to overcome friction between the bar and the rolls). Friction torque equals the product: Compression force (P) times coefficient of friction (M) times radius of roll neck (R). If the roll neck radius is large compared to the roll radius (as in sheet mills) the torque for overcoming neck friction may easily be twice or thrice the value of the torque required for compressing the bar. It is mainly this great variability of roll neck friction that makes comparisons between mills so difficult; unless the mills are of the same design, and unless they roll similar products.

When the roll necks are equipped with roller or ball bearings, or with high grade flood-oil bearings, the coefficient of friction for a given set of conditions is more nearly uniform than when sliding bearings are used. It does, however, vary to some extent with the magnitude of the load to which the bear-

ing is subjected, with the temperature of the bearing, and with the concentration of pressure due to deflection of the roll. In comparing the coefficient of friction of ball or roller bearings with those of sliding bearings, caution must be observed, because the former is usually expressed as a lever arm. To illustrate this statement, Fig. 309 was drawn. The downward force P represents the normal or radial load on the roll neck. For slid-

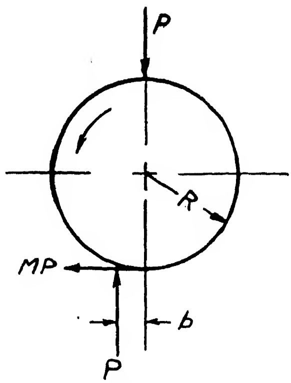


Fig. 309

ing bearings which have a coefficient of friction M, the tangential friction force is MP, and the friction torque is MPR. For antifriction bearings, the coefficient of friction is usually expressed as the length of lever arm b, so that the friction torque is equal to Pb. When the coefficient is expressed in this way, it must, of course, be stated in inches or in some other unit of length. For purposes of comparison, the following relation should be observed: The coefficient expressed as a lever arm is equal to the ratio (tangential force ÷ normal force) multiplied by the radius of the roll neck. The coefficient of friction of roller or ball neck bearings may be as low as 0.0007-inch and sometimes rise as high as 0.10-inch. The ratio of tangential force to normal force in antifriction bearings (including high-grade flood-oil bearings) varies commonly from 0.001 to 0.02, and probably has an average value of 0.005.

As previously stated, the torque required to overcome roll neck friction must be added to the torque required to compress

the bar (and to overcome friction between the bar and the rolls). Hence the total torque at the roll necks, per roll

$$= \text{separating force, pounds} \times (\text{lever arm, inches} + MR),$$

where M is the coefficient of neck friction, and R is the neck radius. Then the horsepower required to drive *each* roll

$$= \frac{\text{force, pounds} \times 2\pi \times \text{r.p.m.}}{12 \times 33{,}000} \times (\text{lever arm, inches} + MR).$$

Instead of using the term "lever arm + MR" in this equation, it is usually more convenient to introduce the roll neck friction factor k such that the (net power required for rolling, excluding roll neck friction) $\times$ k is equal to the total power delivered to the rolls. Then the total horsepower delivered to *both* rolls

$$= \frac{\text{force, pounds} \times \text{lever arm, inches} \times 4\pi \times \text{r.p.m.}}{12 \times 33{,}000} \times k$$

and

$$k \times \text{lever arm} = \text{lever arm} + MR,$$

from which

$$k = 1 + \frac{MR}{\text{lever arm}}$$

From this last relation it is apparent that the neck friction factor k increases as the lever arm of the separating force decreases. For instance, if the value of M in a given case in which plain bearings are used is 0.07, if R is 8 inches, and the length of the lever arm is 1.30 inches,

$$k = 1 + \frac{.07 \times 8}{1.30} = 1.43.$$

This means that the total power delivered to the rolls is equal to

$$1.43 \times (\text{the net power requirement, excluding roll neck friction});$$

or, in other words, that about 30 per cent of the total power delivered to the roll is consumed in overcoming roll neck friction. If the same mill is then used for rolling thinner material, so that the length of lever arm = 0.70 *inches*, the value of k in that case becomes

$$1 + \frac{.07 \times 8}{0.70} = 1.80.$$

In that case, the power required to overcome roll neck friction would be 0.80/1.80, or about 42 per cent of the total power delivered to the rolls.

To demonstrate the general method of calculating the power requirements for rolling and for overcoming roll neck friction, two examples are given in Table XXVII and Table XXVIII. The values in the first table refer to the rolling of strip; in which case the shape of the projected contact area is, of course, rectangular, and the distance from the line of roll centers to the "mass center" is one-half of the projected length of contact. In cases such as this, it is unnecessary to calculate the distance to the mass center; it is more convenient to estimate the ratio "length of lever arm ÷ projected contact length," and to calculate the length of lever arm on that basis. As may be easily deduced from the previous discussion, the value of the above ratio varies from 0.35 to 0.70 in extreme cases. The estimated value of this ratio and the estimated length of lever arm are shown in Columns 24 and 25 of Table XXVII. Column 27 gives the values of the estimated factor for roll neck friction, which apply in this case to antifriction neck bearings. The calculated values of horsepower, as given in Column 28, do not include the power lost in pinions, reducing gears, and motor or engine. These losses must be calculated from the efficiency of the various parts, and must then be added to the values as given in Column 28, in order to determine the total power requirement of the motor or engine.

In Columns 14 to 20 of Table XXVII are shown the calculated changes in temperature which the bar undergoes during rolling. These calculations were made by means of the formulae which were given on pages 51-55 of Vol. I, and which are evaluated in this case as follows:

1. Temperature drop due to contact

$$\frac{0.75 \times 2.24\ (T_s - T_r) \times \sqrt{\text{time of contact, seconds}} \times \text{total area of contact, square feet}}{\text{weight of bar, pounds}}$$

$$= \frac{0.75 \times 2.24\ (T_s - 200) \times \sqrt{\text{time of contact, seconds}}, \times 2 \times 30 \text{ inches} \times \text{average length, feet}}{4280 \times 12}$$

TABLE XXVII

Calculation of forces, temperatures, and power requirements during the rolling of 3" × 30" × 14' slabs to 1/16" × 30" strips
Weight of slab — 4280 pounds

1 Pass No.	2 Leaving Thickness, inches	3 Width, inches	4 Leaving Length, feet	5 Draft, inches	6 Reduction, %	7 Roll Radius, inches	8 Projected Contact Length, inches	9 Contact Length ÷ Average Thickness	10 Projected Contact Area, (Col. 8 × Col. 3) sq. in.	11 Angle of Contact, degrees	12 Roll Speed, R.p.m.	13 Bar Speed Delivered, F.p.m.
0	3.0	30	14									
1	1.80	30	23.3	1.20	40.00	8.0	3.040	1.27	91.20	22.30	19	79.6
2	1.25	30	33.6	0.55	30.6	6.5	1.87	1.23	56.1	16.73	38	129
3	0.75	30	56	0.50	40.0	6.5	1.785	1.785	53.5	15.9	38	129
4	0.375	30	112	0.375	50.0	6.5	1.55	2.76	46.5	13.8	38	129
5	0.240	30	175	0.135	36.0	6.0	0.898	2.92	27.0	8.6	52	163.5
6	0.155	30	271	0.085	35.4	6.0	0.712	3.61	21.4	6.82	80	251
7	0.111	30	378	0.044	28.4	6.0	0.514	3.86	15.4	4.9	112	352
8	0.083	30	506	0.028	25.2	6.0	0.410	4.23	12.3	3.92	150	471
9	0.0675	30	622	0.0155	18.7	6.0	0.305	4.06	9.15	2.92	184	579
10	0.062	30	677	0.0055	8.15	6.0	0.182	2.81	5.46	1.73	200	628

(Continued on opposite page)

TABLE XXVII
(*Continued from opposite page*)

Temperature Entering, °F. 14	Time of Contact, seconds 15	Temperature Drop Due to Contact, °F. 16	Temperature Gain Due to Compression, °F. 17	Temperature Leaving, °F. (Col. 14 + Col. 17. − Col. 16) 18	Time of Radiation, seconds (Estimated) 19	Temperature Drop Due to Radiation, °F. 20	Rate of Compression, 1/seconds (Col. 6 ÷ Col. 15 x 100) 21	Resistance to Compression (Estimated) 1000 lbs./sq. in. 22	Total Separating Force, (Col. 22 x Col. 10) 1000 lbs. 23	Estimated Ratio Lever Arm ÷ Contact Length 24	Estimated Lever Arm, inches (Col. 24 x Col. 8) 25	Torque for Each Roll, not including Roll Neck Friction, 1000 ft. lbs. (Col. 25 x Col. 23 ÷ 12) 26	Estimated Neck Friction Factor 27	Estimated Horsepower Required at Roll Necks 28	PASS Number 29
		Furnace		2200	24.0	50.5									
2150	.1955	31.5	10.3	2129	13.44	31.3	2.1	8.3	758	.55	1.67	105.8	1.20	919	1
2098	.0735	28.7	9.1	2079	13.55	41.8	4.2	11.0	618	.51	0.955	49.2	1.20	854	2
2037	.0697	42.6	15.8	2010	23.6	106.0	5.7	13.6	727	.50	0.392	54.1	1.20	940	3
1904	.0605	69.1	35.2	1870	32.4	228.0	8.3	21.7	1010	.50	0.775	65.3	1.20	1135	4
1642	.0276	67.0	37.3	1612	3.9	26.7	13.1	36.7	993	.50	0.449	37.2	1.30	960	5
1585	.0142	72.0	38.5	1551	2.51	23.4	24.9	38.6	826	.50	0.356	24.6	1.35	1012	6
1528	.0073	72.0	29.6	1486	1.8	20.5	38.9	39.3	605	.50	0.257	13.0	1.40	773	7
1465	.0044	72.8	28.2	1420	1.33	17.8	57.3	43.0	530	.50	0.205	9.1	1.50	777	8
1402	.0027	69.0	25.3	1358	1.09	(15.7)*	70.5	54.0	502	.50	0.152	6.4	1.50	718	9
1350	.0014	(55.0*)	(8.7)	1350	—	—	56.6	46.0	251	.50	0.091	1.9	1.70	245	10

*Heat Losses in these passes insufficient to absorb latent heat at recalescence, hence temperature remains at about 1350°F.

$$= \frac{(T_s - 200) \times \sqrt{\text{time of contact, seconds}} \times \text{average length, feet.}}{510}$$

(for Table XXVII only)

The coefficient 0.75 indicates that the insulating layer of steam between the bar and the rolls transmits only 75 per cent of the heat which would be lost through metallic contact. This value of the coefficient, and the roll temperature of 200 degrees, were chosen by comparison with actual operating conditions in the hot rolling of strip.

2. Temperature gain due to compression

$$= 2 \times \frac{\text{average length, feet} \times \text{lever arm, inches} \times \text{force, pounds} \times 1.286 \times 10^{-3}}{\text{roll radius, inches} \times 0.17 \times \text{weight, pounds}}$$

$$= \frac{\text{average length, feet} \times \text{lever arm, inches} \times \text{force, pounds}}{284 \times 10^{3} \times \text{roll radius, inches}}$$

(for Table XXVII only)

(The figure 1.286×10^{-3} is the heat equivalent of mechanical energy, or 1/778).

3. Temperature drop due to radiation

$$= \frac{0.11 \times (\text{radiating area, square feet}) \times (\text{time of radiation, hours}) \times \left(\frac{T_s + 460}{100}\right)^4}{0.17 \times \text{weight, pounds}}$$

$$= \frac{0.11 \times (\text{radiating area, square feet}) \times (\text{time of radiation, seconds}) \times \left(\frac{T_s + 460}{100}\right)^4}{0.17 \times 3600 \times 4280}$$

$$= \frac{(\text{radiating area, square feet}) \times (\text{time of radiation, seconds}) \times \left(\frac{T_s + 460}{100}\right)^4}{23.8 \times 10^{6}}$$

(for Table XXVII only)

The coefficient 0.11 is called the radiation coefficient, and its value depends upon the condition of the surface of the bar. The value 0.11 applies to smooth, moderately polished surfaces, and was chosen in this case by comparison with operating conditions. The temperature drop of the bar between the furnace and the scale-breaker, however, was calculated with a coeffi-

cient of 0.14, because the scaled surface of the slab radiates heat more rapidly (unless the layer of scale is thick and loosely attached to the steel).

As an example, Pass No. 5 of Table XXVII will be figured through. The width, in this mill, is kept practically constant by edging rolls. Leaving length (Column 4)

$$= 14 \text{ feet} \times \frac{30 \text{ inches} \times 3 \text{ inches}}{30 \text{ inches} \times 0.24 \text{ inches}} = 175 \text{ feet.}$$

Draft (Column 5)

$$= 0.375 \text{ inches} - 0.240 \text{ inches} = 0.135\text{-inch.}$$

Reduction (Column 6)

$$= \frac{0.375 \times 30 - 0.240 \times 30}{0.375 \times 30} \times 100 \text{ per cent} = 36.0 \text{ per cent}$$

Projected contact length (Column 8)

$$= \sqrt{6.00^2 - (6.00 - \tfrac{1}{2} \times 0.135)^2} = 0.898\text{-inch.}$$

Projected contact area (Column 10)

$$= 0.898 \times 30 \text{ inches} = 26.94 \text{ or } 27 \text{ square inches.}$$

Angle of contact (Column 11)

$$= \sin^{-1}\left(\frac{0.898}{6.00}\right) = 8.6 \text{ degrees.}$$

Bar speed delivered (Column 13)

$$= 2\pi \times \frac{6.00}{12} \times 52 \text{ r.p.m.} = 163.5 \text{ feet/minute,}$$

on the assumption that this is the same as the peripheral speed of the roll. From figures for the preceding passes, the temperature of the bar entering Pass No. 5 is found to be 1642 degrees F. Average length of bar in this pass

$$= \frac{112 + 175}{} = 143 \text{ feet.}$$

Time of contact (Column 15)

$$= \frac{8.6 \text{ degrees} \times 60}{360 \text{ degrees} \times 52 \text{ r.p.m.}} = 0.0276\text{-second.}$$

Temperature drop due to contact (Column 16) from page 203

$$= \frac{(1642 \text{ degrees} - 200 \text{ degrees}) \times \sqrt{0.0276 \times 143}}{510} = 67.0 \text{ degrees F.}$$

Before the temperature gain due to compression (Column 17) can be figured, it is necessary to find the resisting force and the lever arm. The rate of compression (Column 21)

$$= \frac{0.135 \text{ inches}}{0.375 \text{ inches initial thickness} \times 0.0276 \text{ seconds}} = 13.1.$$

From Fig. 7 of Vol. I, the resisting pressure at 1642 degrees F. and 13.1 compression rate is 27,000 pounds per square inch. This applies only when friction of the bar on the rolls is small, however. In the present case, the contact length is three times as great as the average thickness of the bar in the pass, and a correction must be made.

Referring to Fig. 309-A, the peak of the "pressure-hill" is first found. If x is the distance from the peak to the centerline of the rolls, then, from Vol. I, Fig. 55,

$$(\text{contact length} - x) \times \text{friction coefficient} - \tfrac{1}{2} \text{ draft} = x \times \text{friction coefficient.}$$

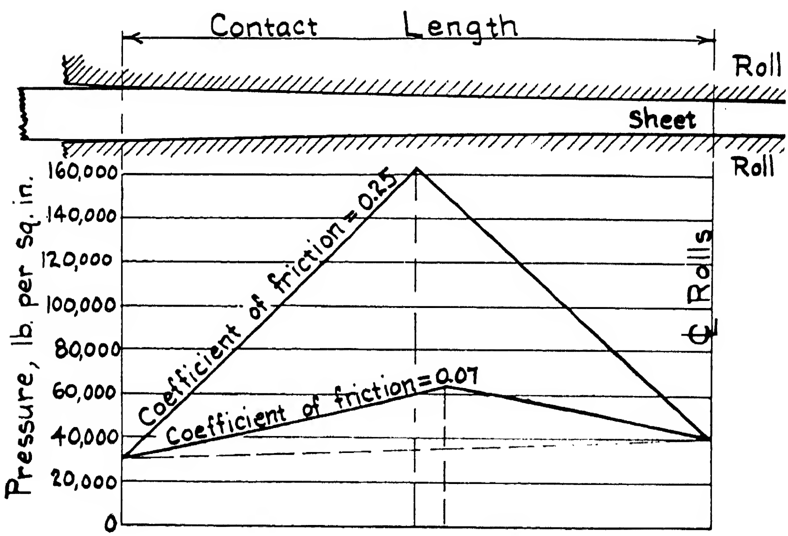


Fig. 309-A

Taking 0.30 as a fair average value for this coefficient, the equation becomes

$$(0.898-x)\times 0.30-\tfrac{1}{2}\times 0.135=0.30x$$

from which, x is found to be 0.337-inch. The maximum horizontal force, ½ H per unit width (referring to Vol. I, page 86 and Fig. 55) is

$$\tfrac{1}{2}H=S\left[0.30\times 0.337+\left(\frac{0.337}{0.898}\right)^2\times\frac{0.135}{2}\right]=0.1107\,S$$

and the horizontal stress is this force divided by half the average thickness of the bar in the pass, or

$$\frac{0.1107S}{0.153}=0.72\,S.$$

The vertical stress is equal to the sum of the horizontal and vertical stresses, or the maximum vertical stress is $S + 0.72\,S$. But at the ends of the contact area, the vertical stress is not increased by pressure, and the average resisting pressure (Column 22) then is approximately

$$\frac{S+0.72+S}{2}=1.36S$$

or $1.36 \times 27{,}000 = 36{,}700$ pounds per square inch. The total separating force (Column 23) is $36{,}700 \times 27.0$ square inches $= 993{,}000$ pounds.

In estimating the lever arm ratio (Columns 24) it is to be considered that the rolls are cylindrical and the contact area rectangular; that the rate of compression is quite high; and that the center of pressure on the basis of the above calculated value of x is almost exactly at the center of the contact length. Hence, from the reasoning of pages 194-196, this ratio should be 0.50, and the lever arm (Column 25) $= 0.50 \times 0.898 =$ 0.449-inch.

Returning to Column 17, the temperature gain due to compression, from page 204 is

$$\frac{143 \text{ feet average length} \times 0.449 \text{ inch lever arm} \times 993{,}000 \text{ pounds, force}}{284{,}000 \times 6.00 \text{ inches roll radius}}=37.3 \text{ degrees F.}$$

and the temperature leaving the rolls (Column 18) = 1642 + 37 − 67 = 1612 degrees F.

Radiating area

$$= \frac{2 \times (0.24\text{-inch thick} + 30 \text{ inches width}) \times 175 \text{ feet length}}{12} = 880 \text{ square feet.}$$

Temperature drop by radiation, page 204, between passes Nos. 5 and 6 (Column 20),

$$= \frac{880 \text{ square feet} \times 3.9 \text{ seconds} \times \left(\frac{1612 + 460}{100}\right)^4}{23{,}800{,}000} = 26.7 \text{ degrees F.}$$

TABLE XXVIII

Calculation of forces, temperatures, and power requirements during the rolling of 9″x8″x8′ blooms to 2½″ x 2⅜″ billets.

Weight of Bloom—1760 lbs. Speed of Mill—83.5 R.P.M.

Pass No. 1	Maximum Dimensions of Leaving Section: Thickness, in. 2	Width, in. 3	Length, ft. 4	Area, sq. in. 5	Draft, sq. in. 6	Reduction, % 7	Maximum Draft, in. 8	Minimum Roll Radius, in. 9	Projected Contact Area, sq. inches 10	Maximum Projected Contact Length, in. 11	Maximum Angle of Contact, degrees 12	Distance to C. G. of Contact, in. 13	Bar Speed Delivered, F.p.m. 14
0	9.0	8.0	8.0	64.8	...	...	...	...	....	...	...	...	...
1	8.0	8.0	8.5	60.6	4.2	6.5	1.00	7.53	21.60	2.70	21.1	1.08	329
2	7.0	8.13	9.7	53.5	7.1	11.7	1.00	7.78	11.1	2.74	20.7	1.10	340
3	7.0	7.0	11.2	46.2	7.3	13.7	1.13	8.03	20.7	2.96	21.1	1.18	350
4	6.0	7.13	13.1	39.6	6.6	14.3	1.00	8.28	20.1	2.84	20.1	1.14	361
5	6.0	6.13	14.8	35.0	4.6	11.6	1.13	8.53	18.6	3.06	21.1	1.22	372
6	5.0	6.31	17.9	29.0	6.0	17.1	1.00	8.78	18.0	2.92	19.5	1.17	383
7	5.0	5.13	21.3	24.3	4.7	16.2	1.31	8.97	17.0	3.36	22.0	1.34	392
8	4.0	5.38	26.4	19.64	4.66	19.2	1.13	9.31	16.6	3.20	20.0	1.28	407
9	4.38	4.31	27.6	18.75	.89	4.5	1.00	9.06	12.4	2.98	19.2	1.19	396
10*	4.81	5.5	32.8	15.81	2.94	15.7	0.94	8.91	10.6	3.18	20.9	1.27	433
11	4.44	4.94	38.7	13.40	2.41	15.2	1.06	9.03	9.15	3.05	19.8	1.22	436
12	4.0	4.75	48.1	10.77	2.63	19.5	0.94	9.31	8.20	2.73	17.1	1.09	450
13	3.63	4.19	57.5	9.02	1.75	16.2	1.12	9.44	8.32	3.21	19.9	1.29	458
14	3.25	3.88	71.3	7.28	1.74	19.3	0.94	9.69	7.16	2.98	17.9	1.19	460
15	3.25	3.50	73.3	7.08	0.20	2.7	0.63	9.63	5.20	2.44	14.7	0.98	459

* Note: Passes 10 to 15, inclusive, are diamond passes, and the dimensions of the section given in columns 2 and 3 are diagonal dimensions.

(Continued on opposite page)

TABLE XXVIII

(Continued from opposite page)

Temperature Entering, °F. 15	Time of Contact, seconds 16	Temperature Drop Due to Contact, °F. 17	Temperature Gain, Due to Compression, °F. 18	Temperature Leaving, °F. 19	Time of Radiation, seconds 20	Temperature Drop Due to Radiation, °F. 21	Rate of Compression, 1/seconds 22	Resistance to Compression 1000 lbs./sq. in. 23	Total Separating Force, 1000 lbs. 24	Estimated Ratio: Lever Arm ÷ Distance to C. G. 25	Estimated Lever Arm, inches 26	Torque for Each Roll, not including Neck Friction, 1000 ft. lbs. 27	Estimated Neck Friction Factor 28	Estimated Horsepower Required at Roll Necks 29	Pass No. 30
....	....	Furnace	...	2100	28.6	36.0	...	...	...	...	...	...	...	....	..
2064	.0421	4.0	2.0	2062	6.7	6.2	1.54	9.1	194	1.10	1.19	19.3	1.43	880	1
2056	.0413	4.4	2.5	2054	6.7	6.7	2.83	10.0	221	1.04	1.14	21.1	1.43	961	2
2047	.0421	4.4	3.0	2045	6.9	7.3	3.25	10.8	224	1.02	1.20	22.4	1.41	1007	3
2038	.0401	5.0	3.3	2036	7.2	8.2	3.56	11.2	225	1.02	1.17	22.0	1.44	1008	4
2028	.0421	5.1	3.5	2024	7.6	9.0	2.76	10.5	195	1.05	1.28	20.8	1.42	940	5
2015	.0389	5.8	4.1	2013	7.8	10.1	4.40	12.3	221	1.01	1.18	21.7	1.44	998	6
2003	.0439	6.0	5.3	2003	28.1	38.0	3.69	12.1	206	1.02	1.37	23.6	1.40	1055	7
1965	.0400	7.0	6.5	1964	8.6	12.6	5.37	14.0	232	1.00	1.28	24.8	1.47	1160	8
1951	.0383	6.2	4.0	1949	9.1	12.7	1.17	9.7	120	1.10	1.30	13.0	1.47	609	9
1936	.0417	12.6	5.7	1929	9.6	13.0	2.71	14.6	155	0.99	1.26	16.3	1.44	750	10
1916	.0395	12.8	6.3	1909	10.5	14.6	3.85	17.2	157	0.97	1.18	15.4	1.47	720	11
1894	.0341	13.4	6.8	1887	11.7	18.3	5.72	20.0	164	0.95	1.04	14.3	1.54	703	12
1869	.0397	15.5	9.0	1862	13.0	20.9	4.08	18.6	155	0.95	1.22	15.8	1.47	740	13
1841	.0357	16.0	10.2	1835	14.7	25.1	6.30	22.0	158	0.95	1.13	14.9	1.51	717	14
1810	.0293	15.3	6.9	1804	...	...	5.54	22.2	116	0.95	0.93	9.0	1.65	473	15

Hence the bar entering Pass No. 6 has a temperature of 1612 — 27 = 1585 degrees F.

The torque on one roll (Column 26)

$$= \frac{993{,}000 \text{ pounds force} \times 0.449\text{-inch lever arm}}{12} = 37{,}200 \text{ pound feet,}$$

and the estimated horsepower required for Pass No. 5 is

$$\frac{2 \times 2\pi \times 37{,}200 \times 52 \text{ r.p.m.} \times 1.30 \text{ roll neck friction factor}}{33{,}000} = 960 \text{ horsepower.}$$

The calculations for the strip mill, Table XXVII, have been checked with actually measured values, both of temperatures and of power requirement, obtained in tests on several differ-

ent hot strip mills, and were found to coincide closely with these values.

Table XXVIII shows the results of similar calculations for a series of billet passes. The temperatures and forces were calculated in the manner just described, and the values of torque were calculated by estimating the value of the ratio "lever arm ÷ distance to mass-center of projected contact area." The estimated values of roll neck friction factor and of power requirements are shown in Columns 28 and 29, and are based on the use of ordinary sliding neck bearings, in which the coefficient of friction is assumed to be 0.07.

Tables XXVII and XXVIII are shown here as illustrations of a problem with which the roll designer is sometimes faced; namely, the determination of intermediate and final temperatures of the bar, and of the power requirement in each pass, from the previously determined dimensions of the starting section and of the passes. An exact solution of such a problem, particularly with regard to the temperatures, can be obtained only by trial, because the values of the coefficients of the formulae vary greatly with apparently slight changes in operating conditions. Calculations such as these must therefore be regarded only as approximations.

Alloy steels require more power for rolling than does ordinary mild steel. In Table XXIX, data are given for the ratio of the power required for rolling various alloys, to the power required for rolling ordinary mild steel at the same temperature (from *Stahl und Eisen*, Dec. 12, 1929).

TABLE XXIX

Material					
Fe.	Ni.	Cr.	Mo.	Rolling temperature, degrees F.	Ratio of power required to that of mild steel at the same temperature
100	. .	. .		2300	1.00
50	50	. .		2120	1.62
20	63	17		2100	2.31
16	62	15		2100	3.86
. . .	80	20		2100	3.08
. .	100	. .		2100	1.27

The power requirement for rolling is frequently expressed in terms of "kilowatt-hours per ton", or "horsepower-hours per ton". These terms are of interest principally to the man who pays the bills, and are of importance to the roll designer only when he wishes to work backward from "horsepower-hours per ton" to the power requirements for rolling. For that purpose, the following relations are used:

$$\text{long tons rolled per hour} = \frac{\text{final cross-sectional area, square inches} \times 2\pi R \times \text{r.p.m.} \times 60 \times 490}{1728 \times 2240}$$

$$= \frac{\text{final cross-sectional area, square inches} \times R \times \text{r.p.m.}}{21}$$

where R = roll radius inches

$$\text{Then, horsepower-hours per ton} = \frac{\text{horsepower}}{\text{tons per hour}}$$

Or, horsepower = (horsepower-hours per ton) × (tons per hour).

For the benefit of those who have to make quick calculations of the power consumption of mills, the curves of Fig.

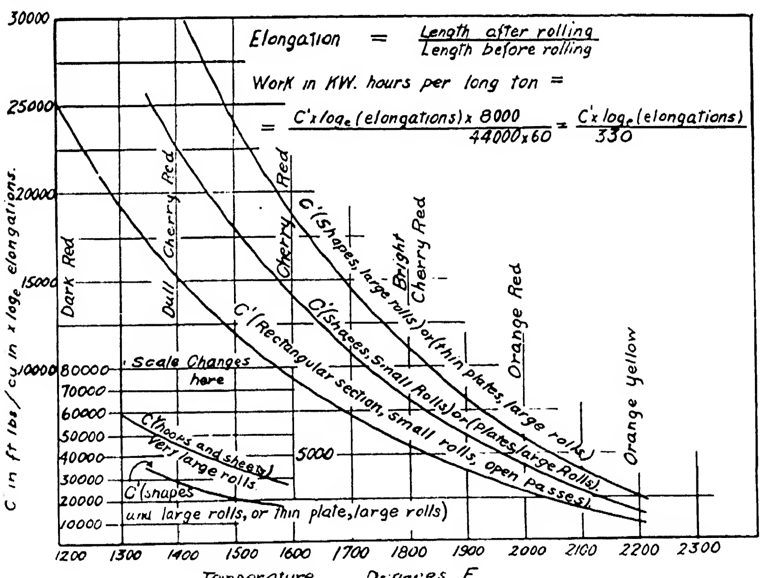


Fig. 310

310 are offered, which were correlated from numerous actual measurements of the power consumption of various mills. The values read from them include roll neck friction, the mills in all cases having had ordinary rough lubrication of the roll necks. As this factor varies greatly from one mill to another, great accuracy cannot be expected from the application of these values to each individual case. They also include power consumed in the pinions, and efficiency of the motor; that is, the figures represent actual input to the motor, hence the power consumption as figured by the use of these curves is usually considerably higher than those obtained by the detailed method exemplified in Table XXVII, because the latter includes neither pinion friction, nor pinion neck friction, nor motor efficiency.

As an example, let 22 x 24-inch ingots be rolled in a blooming mill to 8 x 8-inch billets at an average temperature of 2100 degrees F. The number of elongations

$$= \frac{22 \times 24}{8 \times 8} = 8.25 \qquad \text{Log}_e\ (8.25) = 2.11.$$

From the lowest curve of Fig. 310, the constant $C' = 2000$.

$$\text{Kilowatt-hours per long ton} = \frac{2000 \times 2.11}{330} = 12.8$$

$$\text{Horsepower-hours per long ton} = \frac{12.8}{0.746} = 17.2$$

Where the number of elongations is large, the temperature drop is likely to be considerable, and in that case, instead of trying to estimate an average temperature for the whole rolling process it is best to divide the calculation into several stages, for each of which the average temperature can be estimated more accurately.

APPENDIX

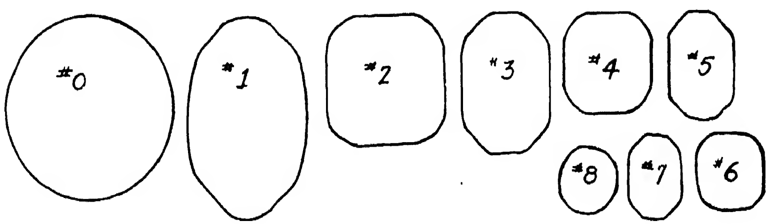
The Rolling of Nonferrous Metals

While steel is the principal metal which is shaped between rolls, it is by no means the only metal. Copper, brass, bronze, aluminum are rolled in all those cases where rolling is either cheaper than extruding or else results in a better quality of product.

As a rule, small sections can be extruded at less cost than they can be rolled, because there is sufficient demand for small sections to warrant the installation of an extrusion press. Large sections are rolled, not only because of cost, but also because large extrusion presses cause too much trouble in operation.

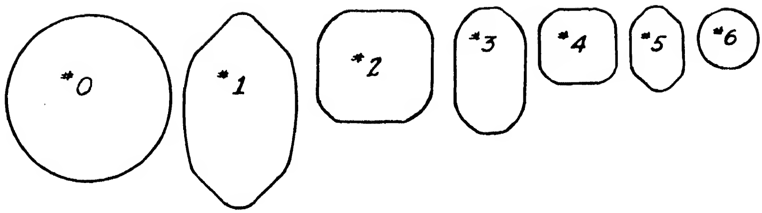
The smallest section which is being rolled varies from one plant to another.

Figs. 311, 312 and 313 (courtesy Bridgeport Brass Co.) show sections which were rolled before the company installed a large extrusion machine. These passes show actual sections



PASS	1	2	3	4	5	6	7	8
AREA	1.33	.97	.75	.55	.425	.296	.254	.214
% RED.	22	27	23	27	23	30	14	14
% SPREAD	7.5	15	9.5	14	9	17.5	10	12
WIDTH	1.61	1.195	1.125	.89	.86	.67	.665	.51
HEIGHT	1.036	1.205	.782	.886	.57	.66	.454	.535

Fig. 311



PASS	1	2	3	4	5	6
%RED.	22	31	35	33	32.3	21
%SPREAD	15	12	13	24	16	11
WIDTH	1.700	1.133	1.105	.759	.726	.5095
HEIGHT	1.016	1.605	.615	.757	.4495	.507

Fig. 312

from cold rolled brass rod, which is made of a mixture containing 65 to 67 per cent copper, with lead running from 1.1 to 1.6 per cent. The same passes are also applicable for mixtures containing 62 to 85 per cent copper without any lead. These rods (with the exception of Pass No. 7 on Fig. 311) were annealed after each pass. The rolls were hard chilled iron, and a little crude oil was allowed to drip into the groove in which rolling took place. In the absence of lubrication, the friction between

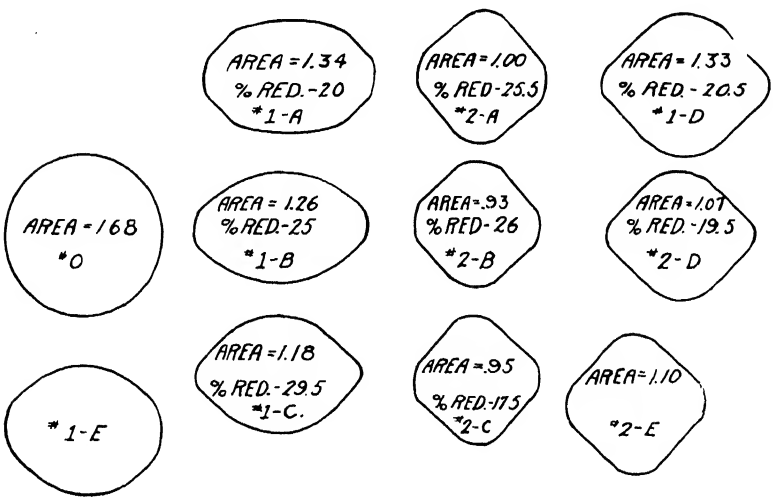


Fig. 313

rolls and bar was sufficient to tear the skin from the surface of the brass. This material built up on the rolls and roughened them. When these rolls were so roughened, the increased coefficient of friction increased the spreading (see Vol. I, page 87), and overfills and even fins were produced.

Fig. 313 shows five different passes No. 1, all of which were used successfully in forming the first pass from the entering round.

In Figs. 314 to 316 a number of passes for hot rolling brass and bronze are offered through the courtesy of the same com-

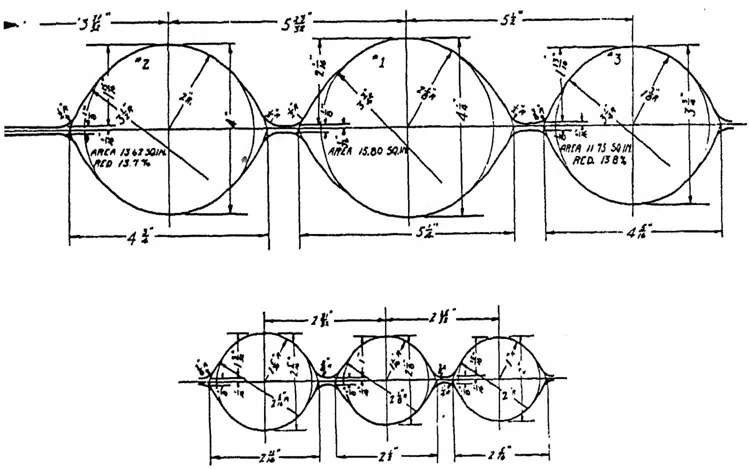


Fig. 314

pany. These passes work successfully on mixtures of the following type: Copper and zinc running from pure copper down to a mixture containing 90 per cent copper and 10 per cent zinc. It is expected these same grooves will work successfully with 80 per cent copper and 20 per cent zinc. The passes work well with copper-tin alloys containing up to 1.8 per cent tin with silicon contents up to 1.0 per cent, also for copper-cadmium alloys containing up to 1.0 per cent cadmium.

Fig. 314 shows a few characteristic passes for hand rounds from a two high mill with steel casting rolls of 50½ inch body

length and with diameters of 16⅛ inch (top roll) and 16 inch (bottom roll). The necks have 10 inch diameter and are 9¾ inches long (each). Very clearly shown is the fact that only a portion of the circumference of the bar is in contact with the rolls.

The reduction inscribed in the passes may be misleading. The values are correct for breaking down, but not for finishing, because the bar is passed through the same groove several times, each time with less reduction, as was explained on page 79.

Fig. 315 offers a series of characteristic diamond passes from a three high mill, having roll diameters of 16⅞ inches (top), 17 inches (middle) and 17⅛ inches (bottom), with roll body length of 50½ inches and neck dimensions of 10 inch diameter by 9½ inches length. The fact that the bottom roll is largest, appears contrary to usual practice. Rolling is done zigzag fashion (see page 180, Vol. I), except that two finishing passes lie in the same vertical plane. The rest of the roll is given over to a square-oval-square reducing series.

Such a series for rolling ½-inch rounds is shown in Fig. 316. For purposes of convenience at the mill these passes lie in

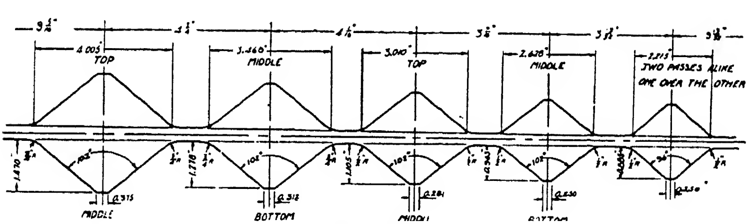


Fig. 315

three different stands, roughing rolls 10 x 24 inches, strand rolls 10 x 20 inches and finishing rolls 10 x 14 inches.

In designing grooves for rolling nonferrous metals the designer should (for the sake of comparison with grooves for steel) know the tensile strength of the nonferrous material at the temperature of rolling, and the coefficient of friction between bar and rolls. That coefficient determines the biting angle, the spreading, and affects the separating force. The tensile strength

(in conjunction with the coefficient of friction) determines the separating force, which latter, as was shown in Vol. I, fixes diameter and length of roll for rolling bars of a given size.

As a rule, the roll designer does not pursue so scientific a

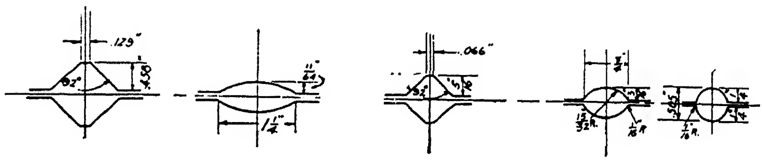


Fig. 316

course, but designs by comparison with rolls and passes which have been used in rolling another size of the same material.

In the absence of such data, the before mentioned information must be available, together with the knowledge of the temperature at which the material can be rolled. As an example for the fact that nonferrous metals offer surprises to the steel man the rolling temperature of aluminum and its alloys may be mentioned. That temperature lies in the range from 700 to 900 degrees F., which is below red heat. At those temperatures, aluminum alloys are just as shiny and bright as cold aluminum. At these temperatures, some aluminum alloys are harder than mild steel is at 2200 degrees F. This fact is well brought out in the curves of power demands for rolling as published by the late R. L. Streeter ("The Rolling and Extrusion of Aluminum and Its Alloys", A. S. M. E., 1932).

From the same publication Figs. 317, 318 and 319 were taken. Fig. 317 shows passes for a 38 inch blooming mill. They reveal the interesting fact, that aluminum spreads top and bottom down to the last pass, while steel spreads top and bottom in the early passes, and then changes to spreading in the center. The difference is due to several facts. Aluminum is rolled at a lower temperature, and does not lose heat as rapidly as steel for that very reason. The surface of aluminum is smooth and bright; for that reason, the radiation of heat, at a given temperature, is less than for steel. Both facts serve to sustain the temperature of the bar. Finally, aluminum is an excellent con-

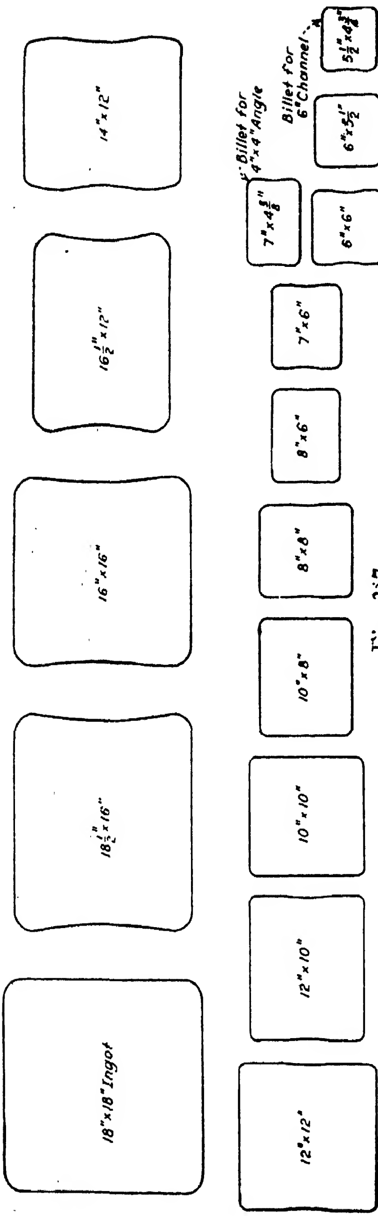


Fig. 317

Fig. 318

Fig. 319

ductor of heat. In consequence, the interior is only a trifle hotter than the surface, and the reason which causes steel to spread in the center is absent. Blooming mill rolls can, therefore, be made cylindrical (without a "belly") in all passes, particularly since ragging is taboo. Since aluminum has a much higher coefficient of friction than steel, ragging is unnecessary.

Figs. 318 and 319 show, respectively, the passes for a 6 inch channel and for a 4 inch by 4 inch angle, both rolled on a 24 inch—26 inch structural mill. No dimensions were given in Mr. Streeter's paper. The design is affected by the great friction of aluminum, which results in great spreading unless the rolls are highly polished.

Few data are available on the resistance to compression or the power consumption in rolling the nonferrous metals. In cold rolling, the average ratios of these quantities to the corresponding values for cold steel are roughly about as follows: Copper, 50 per cent; brass, 90 per cent; aluminum, 25 per cent; zinc, 35 per cent. The ratios vary with the flow-hardening, which in brass, for example is quite high.

Roll Passes for Seamless Tubes

Although piercing rolls have no grooves in their surfaces, the piercing rolls, in conjunction with the plug, form a well defined pass, which changes the tube blank from a solid circular area to an annulus of approximately the same cross section.

Fig. 320, which represents piercing rolls of a late type, illustrates the pass very well. The blank enters at the left, is reduced in cross section and then formed into a tube in the space between rolls and plug. The pass, therefore, consists of a convergent part and a divergent part. The purpose of the divergent part is easily seen, but that of the convergent (or first) part is less apparent.

Before going into this discussion, it may be advisable to mention that the skew rolls turn in the same direction and impart a rapid rotation to the blank, also that the oblique or skew position of the rolls imparts a forward feeding motion to the

blank. Both motions are imparted to the blank solely by friction.

Concerning the design of rolls and of the mandrel, R. C. Stiefel, one of the greatest exponents of the rolling of seamless tubes, gives the following instructions (in a joint paper with Mr. Pugh, May 1928 meeting of American Society of Mechanical Engineers in Pittsburgh):

"Until lately there has been no good and reliable procedure established to determine the most favorable size of solid billet from which to produce a given tube; it has been largely a matter of 'rule of thumb'. A common practice was to choose a solid billet of a diameter approximately the same, or somewhat

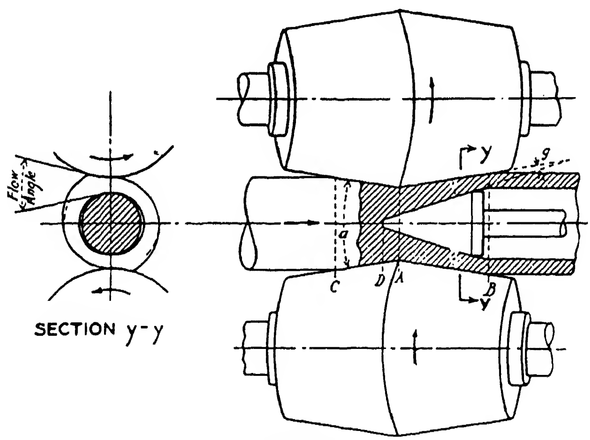


Fig. 320

smaller, than the desired tube. The correct method to determine the most favorable size of solid billet is as follows:

"The piercing diagram illustrated in Fig. 320 is arranged in such a manner that the converging pass *CA* formed between the rolls establishes enough grip on the billet, by the time the latter has progressed to point *D*, to force it over the point of the mandrel. The elongation of the billet, that is, the reduction of its cross-sectional area, should be done only in the converging pass from *C* to *A* with a minimum draft or reduction of the billet.

The diverging pass, from *A* to *B*, between the rolls and the mandrel is arranged so that the cross-sectional area of the billet at *A* is equal to that at *B*. In a piercing pass established to fill these conditions, the billet is only subjected to expansion in the diverging pass and to elongation in the converging pass.

"It will be clear from a closer study of Fig. 320 that the metal of the billet has a fair chance to flow lengthwise (or the billet has a chance to elongate) in the converging pass where it is gripped between the two roll faces forming a comparatively large included angle *a* between them. But where the metal is gripped between the two converging roll faces and the two corresponding mandrel faces, it becomes almost impossible for it to flow lengthwise between the respective roll and mandrel faces which form a smaller flow angle *g* for the metal than is the case in the converging pass. On the other hand, it is evident from the cross section at *yy* of Fig. 320 that the flow angle in the transverse direction is greater than in the longitudinal direction, from which it follows that in the diverging pass the metal meets less resistance to flow in the transverse direction (expansion) than in the longitudinal direction (elongation). From this analysis it becomes clear that the diverging pass should logically be determined, as described, so as to compel expansion, and not elongation of the billet, instead of by using a mandrel the shape of which is determined by guesswork.

"The foregoing procedure of determining the piercing conditions for a given size tube is a sure way to obtain the best results, with reference to punishment of the steel and consumption of power. — — — —

"It will be noted from Fig. 320 that at the first contact *C* established between the billet and the rolls, the diameter of the roll is small while the billet is large; as the billet progresses from *C* to *A*, the diameter or circumference of the billet decreases while that of the roll increases; from *A* to *B* the reverse takes place, that is, the diameter or circumference of the billet increases while the corresponding diameter or circumference of the rolls decreases. This irrational relation between corresponding diameters, and consequently speeds, of the rolls and billets

at different contact points during the progress of the billet through the piercing pass, results in the setting up of injurious stresses in the billet; it also results in the breaking up of the center of the billet before it reaches the point of the mandrel, thereby favoring the penetration of the mandrel into the center of the billet; but it also has the effect of producing enormous friction or slippage between the rolls and the billet on the outside as well as between the mandrel and the billet on the inside. When considering that the metal pressure exerted by the rolls onto the billet may amount to several hundred thousand pounds, it will be evident at once that much slippage under such great pressure will result in enormous waste of power.

"The peculiar functioning of the mandrel in the pass of the now customary piercing machine also greatly contributes to the setting up of injurious stresses in the billet. It is apparent that the rolls, being obliquely disposed in relation to the axis of the billet or pass, tend to rotate the billet and feed it forward over the mandrel. The axis of the billet and the axis of the mandrel being the same, it is clear that the mandrel has no forward feeding effect on the billet; the billet therefore is fed or pulled or pushed forward on the outside by the rolls while the mandrel on the inside tends to prevent it from moving forward.

"Furthermore, it will be noted that to the large diameter of the roll is opposed the small diameter of the mandrel, while to the small diameter of the roll is opposed the large diameter of the mandrel. The torsion and slippage stresses to which the outside of the billet is subjected by the speed differences of the rolls, as explained before, are therefore being repeated for the same reasons on the inside by speed differences of the mandrel. All this occurs under the heavy pressure on the metal necessary to displace it from under the contacting surfaces between it and the rolls and mandrel.

"What has been stated heretofore with reference to power absorption by slippage or friction by the rolls on the outside of the billet, also applies in connection with the similar great friction or slippage occurring between the mandrel and the inside of the billet."

The upshot of this general discussion, stated in different words, is the following: Plastic material flows in the direction of least resistance, that is to say, away from and normal to the

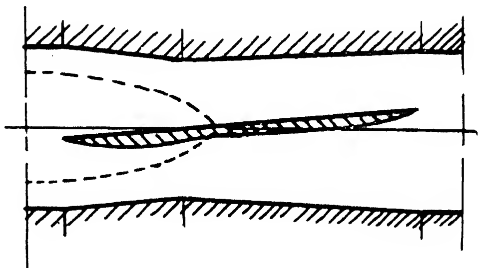


Fig. 321

short side of the projected contact area. The shape of that area, as may be seen from Fig. 321, is very long in the direction of feed and very thin in the direction of motion of the rolls. The initially round billet becomes elliptical between the rolls and flows backward (relative to the feeding velocity of the rolls). Continued change of shape causes sliding of diametral planes over one another, whereby the center is disintegrated. The fact that tension exists in the center of a cross-rolled cylinder is apparent from Fig. 322. The convergent pass, therefore, serves

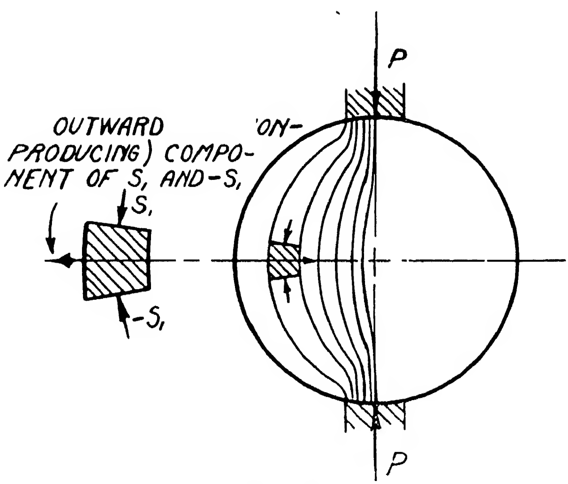


Fig. 322

mainly for purposes of disintegration and for overcoming the resistance of the mandrel. The nose of the plug reaches into the convergent pass and is by experience placed so that practically no hole is formed ahead of the plug, although the material is disintegrated and is ready to form a hole at the least provocation. The rest of the projected contact area serves for enlarging the diameter and for moving the blank ahead against the frictional resistance of the plug.

Mannesmann had hoped to produce finished thin-walled tubes by cross rolling. He could not succeed because the feed forces are too feeble to overcome the additional friction of the longer and larger plug which would be necessary for producing a thin-walled pipe. Under ordinary conditions the wall thickness of the blank is 1/7 to ⅛ of the external pipe diameter. Under favorable conditions it may be 1/10, whereas in the final tube the wall must be much thinner (1/20 of the outside diameter in standard 4½ inch pipe, 1/32 of the outside diameter in 8 inch pipe).

Any device which helps forward motion of the pipe permits the wall thickness to be reduced in the piercing pass. The use of larger rolls helps, but the gain is very small in comparison to the increased cost of the mill. Mannesmann originally used three cross rolls, but did not make them small enough. At any rate, the gain was small. Kocks in Germany has recently used four small rolls and has apparently obtained good results. In the United States, S. Diescher (Pittsburgh) has added high-speed disks top and bottom which lie in the same position as the rolls of a tube welding mill and help to pull the tube blank through the cross rolls. His results have been excellent.

Billets and round ingots can be pierced by the cross rolling method, using a variety of proportions. In the course of 50 years, these have narrowed down to certain limits. The diameter at the high point of the rolls is from 1.75 to 5 times the diameter of the pierced blank. The large value holds for small tubes (3 inch to 4 inch) while the low value holds for large tubes (for instance 12-inch diameter). It should be noted that the ratio is given for the tube blank, and not the finished tube.

The angle between roll and blank (that is to say, the angle between roll and horizontal) is 4½ degrees in European practice, and adjustable from 6 degrees to 12 degrees in American practice, for the purpose of increasing the output for small tubes; the difference is due to the fact that the European piercing methods pierces an ingot and prepares it for the Pilger mill. If the skew angle is too small the forces producing forward feed are too feeble, and the wall thickness of the pierced blank must be very great. If the skew angle is too large, the forward feed is too rapid, and the blank is not properly disintegrated.

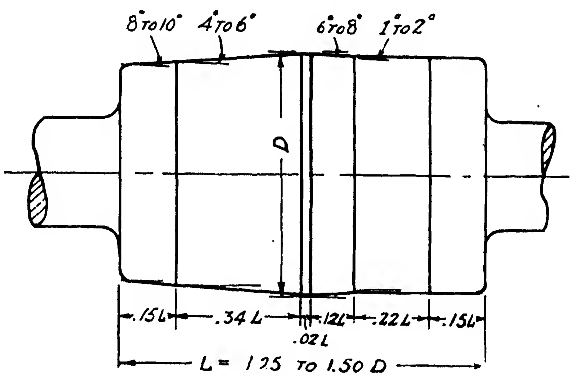


Fig. 323

The cone angle on each side (½ of the total angle of each cone) lies between 5 degrees and 10 degrees. If that angle is too small, the cones must be too long, the projected area becomes too long, backward slip becomes too great, and power is wasted. If the angle is too large, not enough projected contact area is available for forward feeding.

In some mills, a cylindrical band, about 1 inch wide is interposed between the two cones.

It can be seen that the rolls for the piercing process are the result of a compromise between conflicting conditions and that the roll designer has very little freedom of action.

In German practice (which has also been adopted in several mills in the United States), the proportions given in Fig. 323 are

common. In this drawing the maximum roll diameter $d = 1.75$ to 2 times the diameter of the round bloom or ingot entering the mill. These rolls differ from those commonly used in the United States in the following respect: The converging pass consists of two cones, whereby the beginning of the roll has a smaller diameter for a given length of roll) than it would otherwise have. This reduction of diameter is due to the fact that the German Mannesmann process pierces round ingots, which are taper. The long ingots are broken into shorter pieces which, in consequence, have different diameters. The entrance opening must be large enough to grip the largest ingot section. In the seamless tube processes developed in the United States,

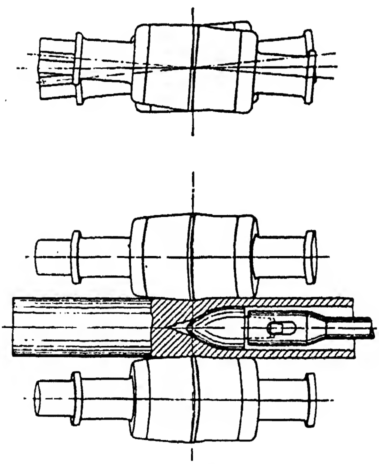


Fig. 324

prerolled rounds enter the piercing mill. They are of uniform size, and the necessity for a break in the entrance cone does not exist.

On the divergent side, the cone angle is greater than on the convergent side. This change of angle helps the forward feed, and permits the use of a plug of parabolic outline, see Fig. 324. The roll is then enlarged again so as to stay in contact with the newly formed tube, for the purpose of smoothing down helical ridges left by the piercing cones and for making the cross-section of the tube truly circular. In the United States,

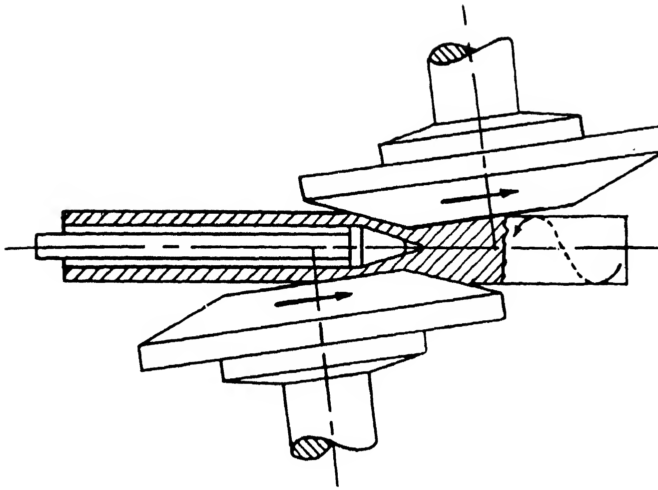
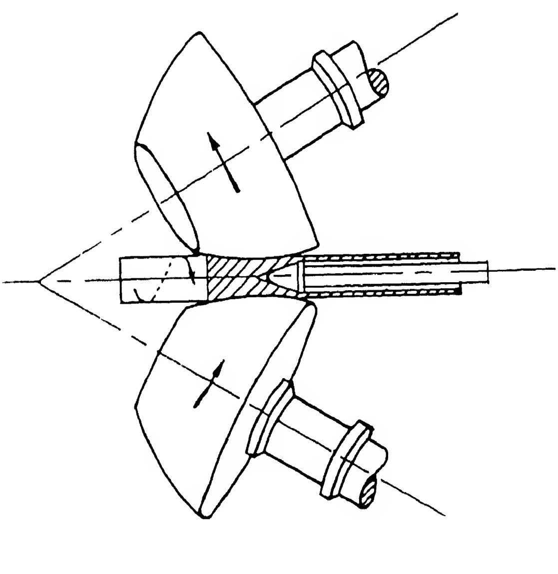


Fig. 325

this "finishing pass" of the piercing rolls is seldom used, with the result that the pierced blanks are rough and irregular. However, that irregularity is not fatal, because it can be smoothed out in further rolling, unless the tube blank is eccentric. To



avoid eccentricity, uniform heating, and guiding of the blank (top and bottom) in the pass between the rolls are necessary.

The convergent-divergent pass, coupled with forward feeding can be had by rolls of shape very different from that of the Mannesmann cross rolls. Stiefel, who went through the experience with early Mannesmann mills in Great Britain, tried to reduce the twisting strains in the round billet by using disks (Fig. 325) or by nearly parabolic cones (Fig. 326). Both types of Stiefel piercers are much used in the United States.

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